(continued from part 34)

Laser scanning

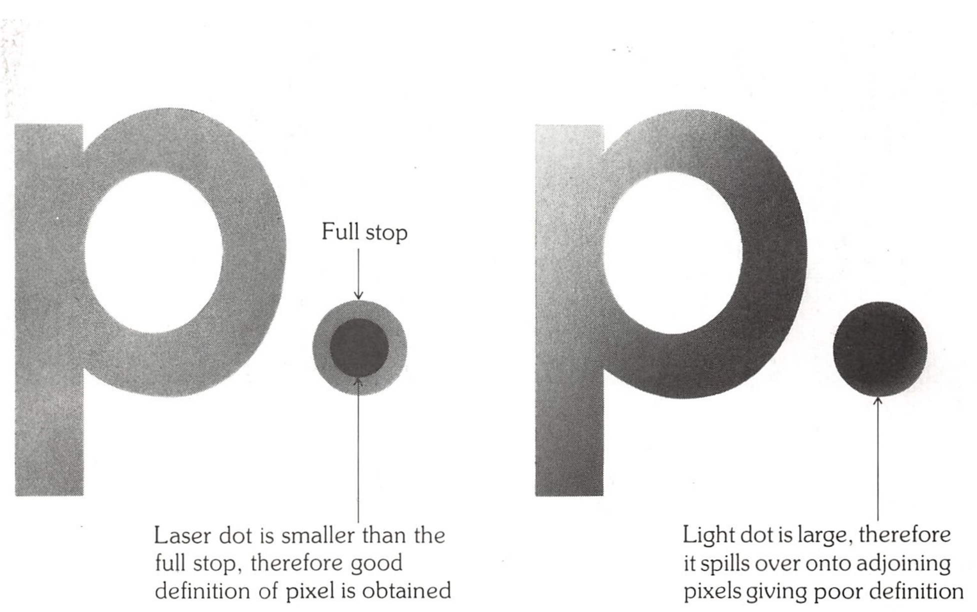
Laser scanners form the most advanced and accurate optical scanning systems. The three important properties of laser light, as we have seen in *Solid State Electronics 21*, are: coherence, unidirectionality and monochromaticity. In addition, laser light may be far more intense than light from any other source.

In a scanning system using a conventional light source, it is necessary to use a very complicated and expensive optical system to focus a tight dot onto the image, and to focus the reflected light onto the photodetector in order for the fine detail of the image to be resolved. However, it is also important for the dot itself to have high definition, because if light 'spills over' into the area surrounding a pixel, the photodetector will pick up information from an adjoining pixel, resulting in loss of resolution (*figure 17*).

Laser light is naturally collimated (i.e. parallel), therefore the optical system required for a laser scanner is less complicated (and hence less expensive) than that needed for a conventional scanning light source. As laser light is also always monochromatic (i.e. the light is all of one frequency), the laser and the photodetector can be matched so that together they operate at the frequency which produces maximum output from the system as a whole. However, a laser's most useful property is its coherence, i.e. all light rays are in phase with each other. This property accounts, in part, for the intensity of laser light because there is no **destructive interference** between the rays at a surface.

Ordinary light, on the other hand, comprises rays with random phase and amplitudes, and when they reach a surface, the out-of-phase rays will partially or completely cancel out (i.e. destructively interfere). The reflected light from a laser beam will also be more coherent, though not as coherent as the incident beam, and so the light reaching the photodetector will be more intense than would be the case with conventional light sources.

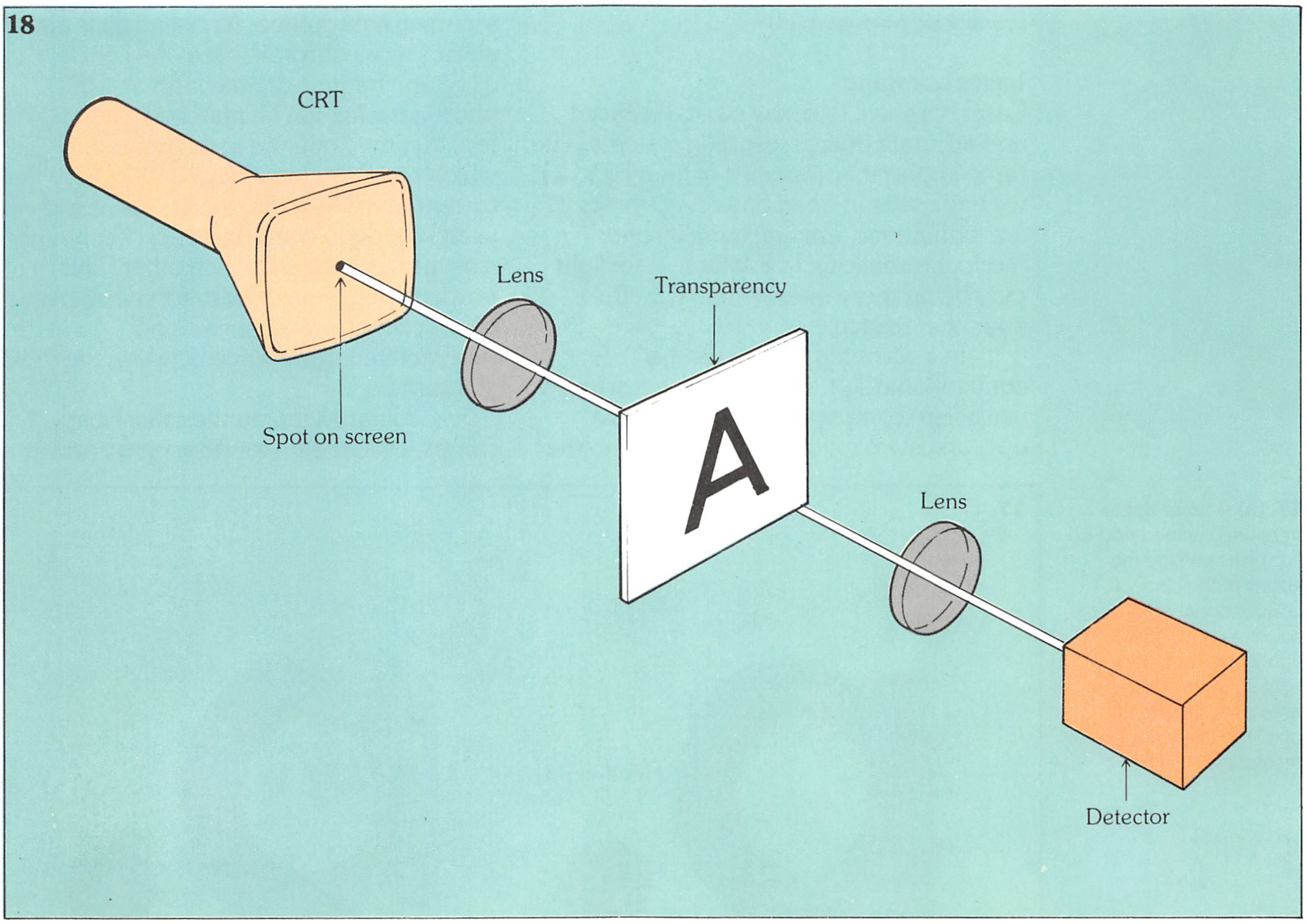
17



17. (a) A laser dot is very well defined and no light falls outside the edges of the circle; **(b)** conventional light sources cannot be as tightly focused, and so light spills over into the area surrounding the pixel resulting in a loss of resolution.

Electronic scanning

The scanning methods discussed so far have one serious disadvantage: they are all mechanical devices and hence suffer from



18. A CRT flying spot scanner.

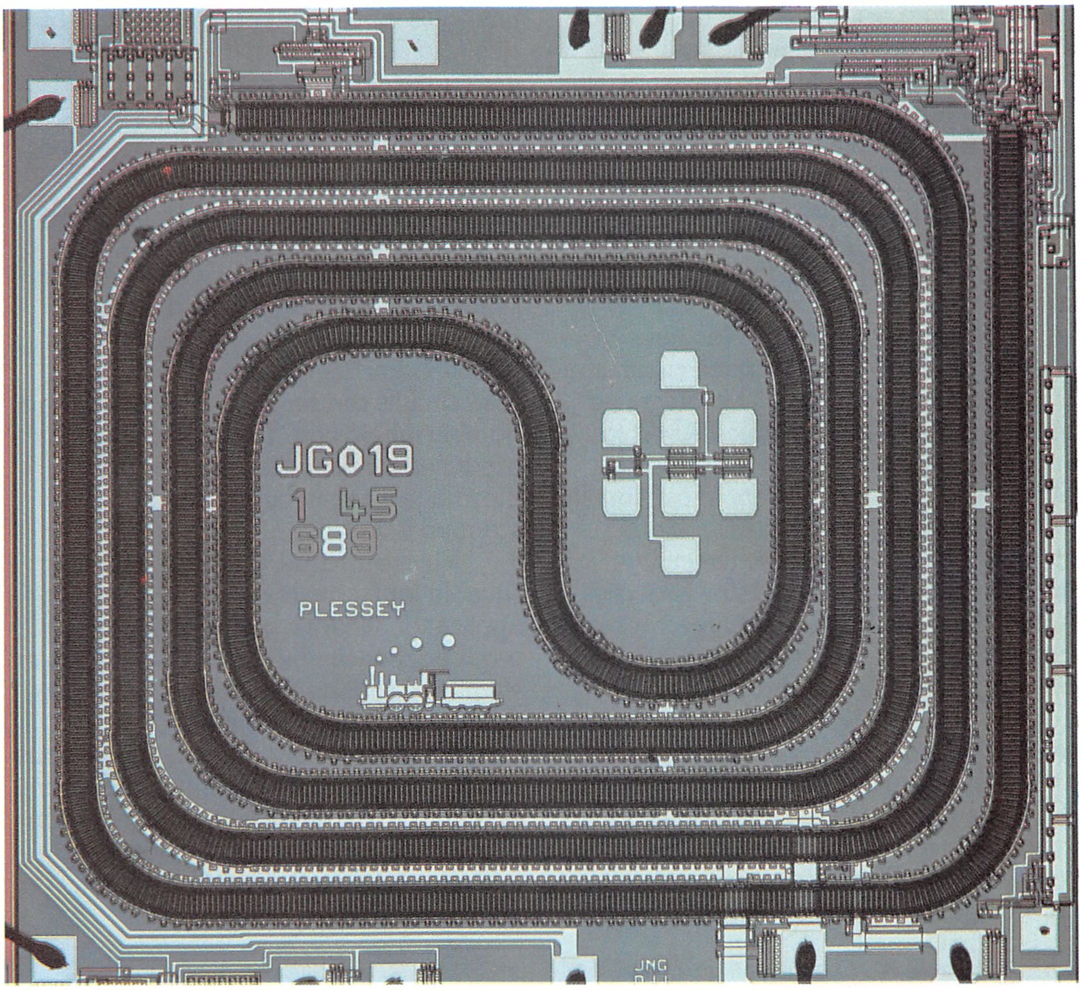
the problems common to all such devices. For example, they can be difficult to align and calibrate, hard to maintain, and liable to break down. Electronic scanning methods, on the other hand, have no moving parts and are therefore much more reliable. However, they can be almost too fast and efficient, producing data so quickly that, as we shall see, standard communications links are unable to cope with the signals produced by such methods.

CRT scanners

A high intensity version of the familiar cathode ray tube (CRT) may be used to produce a **flying-spot scan**, as shown in *figure 18*. In common with all electronic scanning methods, it offers very fast scan speeds and is easy to maintain. However, the intensity of the spot is low, even when special CRT phosphors are used, and its use is limited to source documents comprising only photographic transparencies. The low intensity spot passes through the transparency and is collected and focused onto a photodetector, so the baseband signal produced by this method has an amplitude proportional to the light passed, rather than the light reflected.

Some CRT tubes have a fibre optic faceplate instead of the more familiar clear glass: as light is emitted from a phosphor dot it is conducted via a short length of optical fibre to the surface of the source document. Once again, this method can only be used with photographic transparencies.

An ordinary television camera tube may be used for image sensing, of course. An image of the document is focused onto the photosensitive screen by an optical system and the screen of the tube is raster scanned by the electron beam. A high resolution camera tube produces a video signal which is a very high quality analogue of the image.



Right: a charge coupled device (CCD). This acts like an analogue shift register, or delay line. (Photo: Plessey Semiconductors).

Solid state scanners and sensors

Solid state scanners, which contain built-in sensing elements, are now fairly widespread, particularly for applications where the source documents are black and white only (that is *without shades of grey*). Solid state scanners/sensors offer several advantages over other methods: there are no moving parts and the scanning rate can be very high.

These solid scanners are called linear image sensors (LIS), sometimes known as linear array sensors, and comprise a single integrated circuit with, typically, 1728 photosensitive elements. They are frequently used for sensing A4 sized documents, which measure 210 × 297 mm; each pixel, therefore, is 210/1728 or 0.12 mm wide. Line feed is obtained by moving the paper by rollers.

In solid state facsimile systems the document is usually floodlit, because the array of tiny photosensitive elements itself forms the scan aperture, limiting the pixel area from which light can be detected.

The integrated circuits used as linear image sensors are a specially manufactured version of a charge coupled device (CCD). As we saw in *Digital Electronics 18*, a charge coupled device is a MOSFET-based integrated circuit which can be considered to act as a 'bucket-brigade', allowing buckets of charge to pass along a line. CCDs are therefore ideal for use as *analogue* shift registers, i.e. **delay lines**.

Charge coupled devices for image sensing are made with a quartz window in the top of the IC, through which the elements are exposed to light. There is no electrical input to these arrays; instead, light is allowed to fall on the exposed array during a line scan period. The light liberates charge carriers in the substrate which, of course, collect as charge packets. At the end of a line scan period, the stored

charge packets are shifted out by applying the correct sequence of pulses to the device, forming a serial data stream of analogue voltage pulses where the amplitude of each pulse represents the image at one pixel on the source document. The process of shifting the charges out of the array also empties the buckets, setting them up for the next line scan.

Interestingly, it is possible to use another type of MOS integrated circuit as a whole area image sensor. The integrated circuit is a MOSFET dynamic RAM chip and, as you remember from *Digital Electronics 16*, it is necessary to continually *refresh* the data stored in this type of memory because otherwise the charge stored in each memory cell slowly decays. And, whereas light causes charge packets to occur in a CCD element, it actually discharges a MOS memory cell.

So, a simple whole area image sensor can be formed just by removing the opaque lid from a common MOS dynamic RAM integrated circuit and focusing an image onto the exposed array of memory cells with a simple lens system. The memory is filled with 1s, first, and after a time cells that are exposed to white light decay to 0s, while cells that are 'in the dark' retain enough of their charge to register as 1s.

When the cells have been exposed for long enough, the entire block of memory is read as a stream of 1s and 0s which represent the image. However, unlike the output from a CCD which is a series of analogue voltages, the output from a RAM image sensor is a stream of binary 1s and 0s, because the memory read circuits can sense only 1s and 0s and nothing inbetween. Therefore, the image produced is relatively crude compared to the image that can be obtained from a scanned LIS device.

This technique, therefore, is not suitable for facsimile or any other application where high resolution is required, but can be used, for example, in shape recognition and pattern sensing in automated production lines.

CCD arrays offer far better prospects for high quality image sensing, and a lot of research is underway, the ultimate aim being to develop a solid state video imaging system to replace the current generation of camera tubes.

Glossary

baseband	analogue signal in a facsimile system corresponding to the light levels of individual pixels
destructive interference	interference between light rays from a non-coherent source, which tends to partially or completely cancel out the light
floodlighting	method of illuminating the source document in a facsimile sending unit, where the whole document is illuminated
integrity	wholeness of the image in a facsimile system
linear image sensor	solid state integrated circuit, capable of storing source document images in a facsimile system. Because they are solid state, no mechanical scanning is needed
raster scanning	scanning of the source document of a facsimile system, in a similar way to the scanning of a television CRT screen
spotlighting	method of illuminating the source document in a facsimile sending unit, where only a very small area is illuminated at one time

7

DIGITAL & SOLID STATE APPENDICES

Showing frequency response

Bode plots and decibels

We have seen how it is possible to plot the frequency response of a network as two graphs: the first of these is a graph of the network's voltage ratio (plotted on the vertical axis) and frequency (plotted on the horizontal axis); the second graph is also a plot of frequency on the horizontal axis, but with the network's phase response on the vertical axis.

The voltage ratio of a network is simply the ratio of output voltage to input voltage, i.e. V_o/V_i. So, in effect, the vertical axis of the first graph allows us to plot the network's voltage gain as a function of frequency. At any chosen frequency, therefore, we may use the graph to find out what the network's gain is and so calculate the output signal voltage when an input signal sine wave of known voltage and of that frequency is applied. Of course, the networks we have shown on such graphs until now have been simple passive circuits (resistor/capacitor combinations) which are not capable of amplification so the 'gain' may only be a decrease in voltage from input to output. However, these graphs may equally be used to plot the gain of an active amplifier with respect to frequency.

The phase response of a network is the phase relationship of the output signal with respect to the input signal, or:

$$\phi = \phi_O - \phi_1$$

where: ϕ is the network's phase response; ϕ_I is the phase of the input signal; ϕ_O is the phase of the output signal. The input signal phase may be taken as reference, so:

$$\phi = \phi_O - 0$$

or:

$$\phi = \phi_O$$

so, if the output signal phase shift is $-40°$, we may say the phase response is 40°.

Figure 1a shows plots of voltage ratio and frequency for a simple network – plots of the same network's phase response and frequency are given in *figure 1b*. As before, a logarithmic scale has been used on the horizontal axes so that equal increments correspond to equal multiples of frequency. Such a logarithmic scale allows a number of decades of frequency to be plotted (say, as in *figure 1*, four decades from 1 Hz to 10 kHz) with reasonable accuracy.

A logarithmic scale is actually used for the vertical, voltage ratio scale, too, but this is not apparent because the axis is marked in linear steps. However, the units used on the vertical axis are decibels (dB) which are themselves logarithmic units – we'll say more about decibels later.

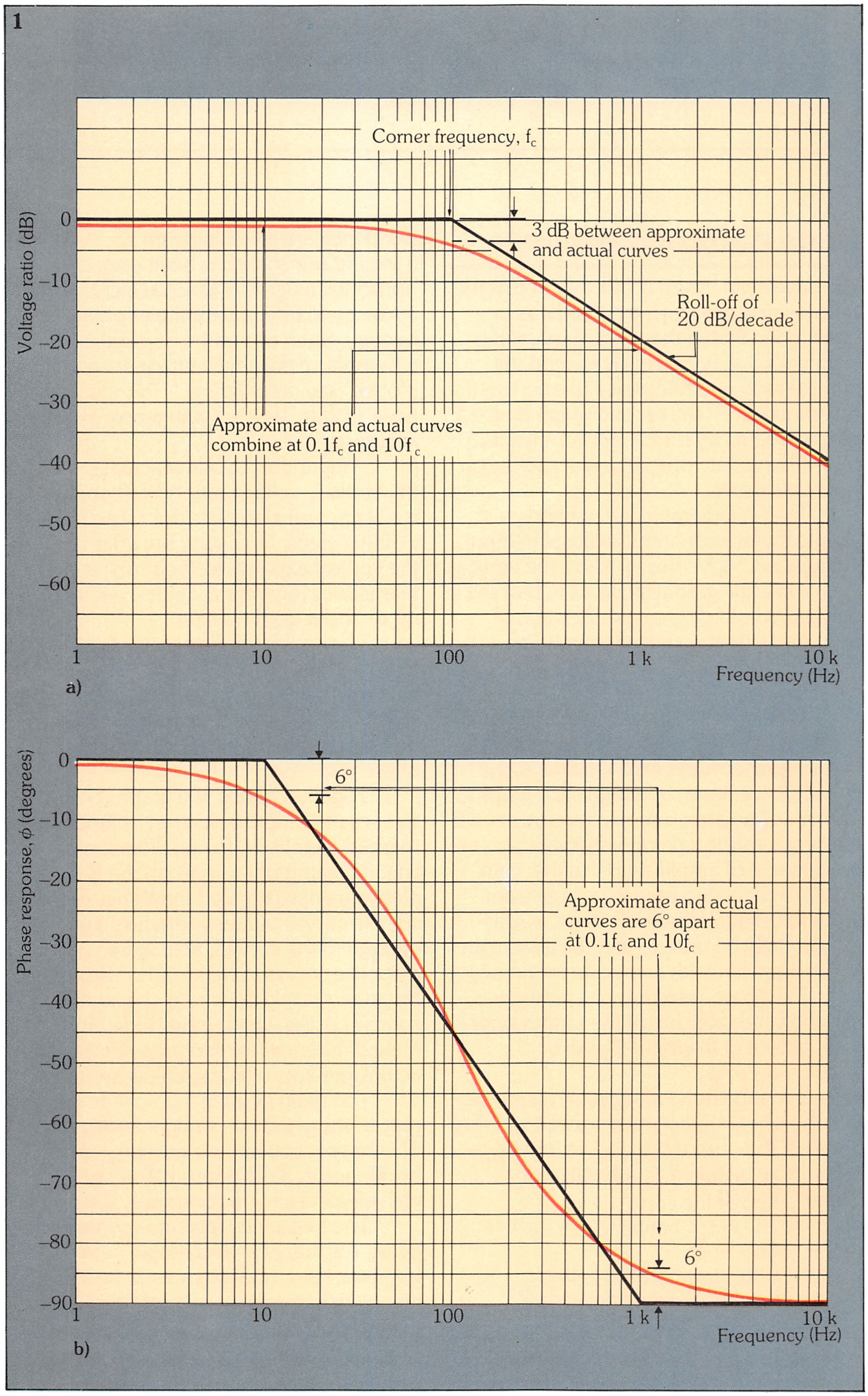
The corresponding plots of phase response and frequency for the same network are shown in *figure 1b*. The same logarithmic frequency scale is used, but here a linear vertical scale is used to plot phase response.

Together, these two graphs of frequency response are known as **Bode plots** (named after H.W. Bode). The straight-line, or asymptotic curves on the Bode plots are approximated frequency response curves but, nevertheless, are close enough to the curved, actual, frequency response curves to make little difference. Engineers rarely need to plot actual response curves when using Bode plots. Main differences at marked points between actual and approximated plots are shown.

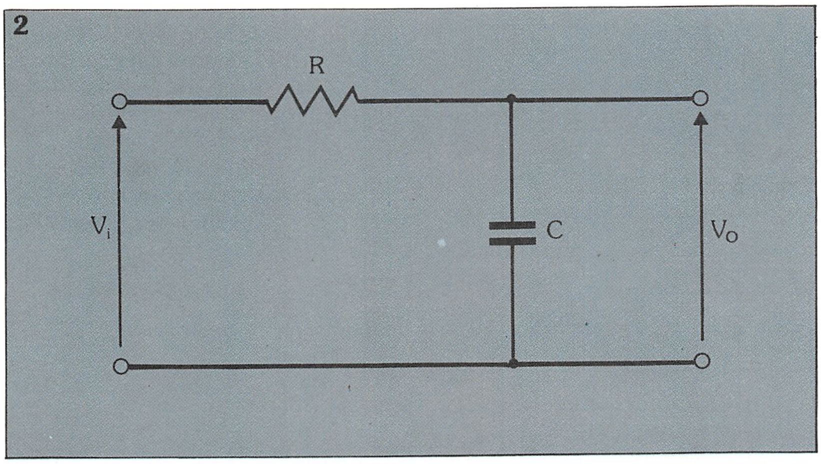
The main point in the voltage ratio plot is where the two straight lines meet. This has several names: **corner point**; **break point**; **3 dB point**; **roll-off point** etc., all of which are commonly used.

The frequency response plotted in *figure 1* is that of a very simple network, a low-pass filter, resistor/capacitor combination, which may be shown in *figure 2*. At this point, the values of the resistor and the capacitor are not important – we'll see now why this is so.

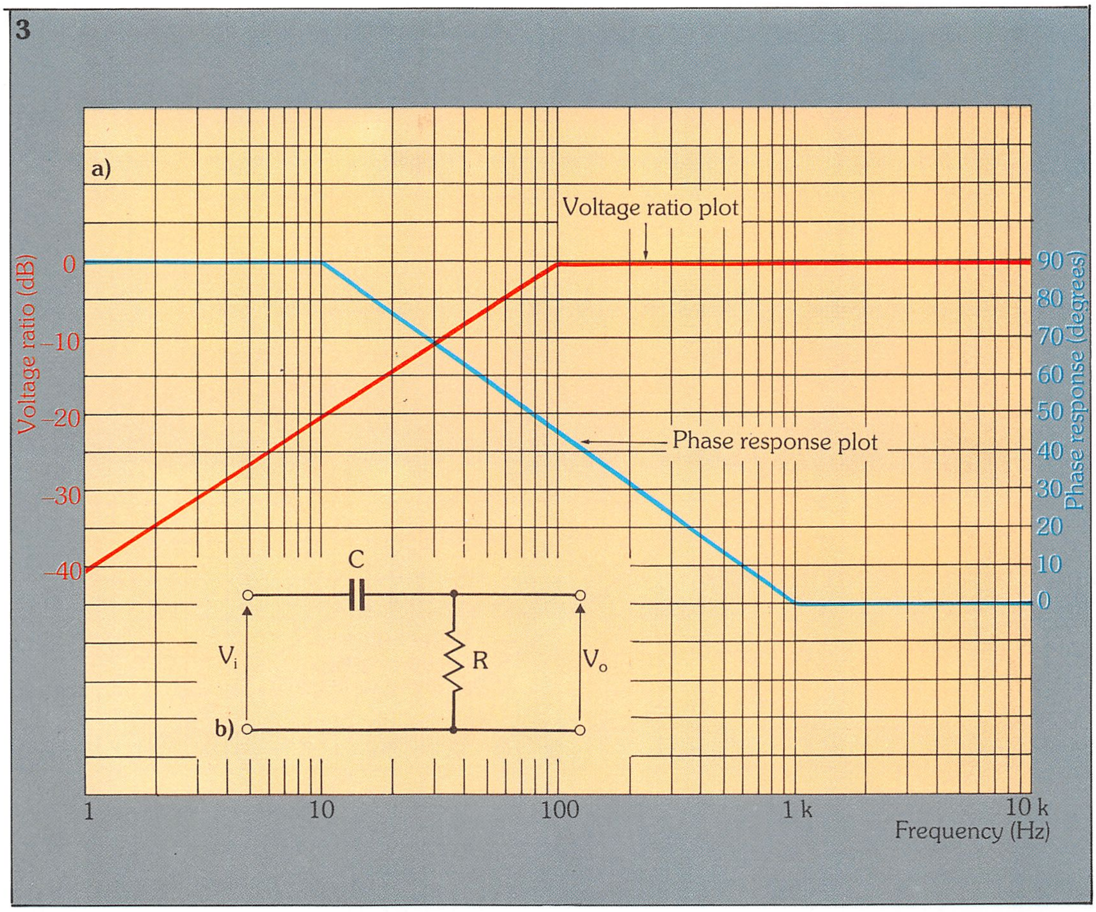
1



1. Bode plots for a simple network; **(a)** voltage ratio *vs* frequency showing the break point or corner point; **(b)** phase response *vs* frequency for the same network.



2. **The simple network** (a low-pass filter, resistor/ capacitor combination) for which the Bode plots are shown in *figure 1*.



3.(a) **Bode plots for the high-pass filter,** resistor/ capacitor network shown in **(b)**.

work whose frequency response is shown in *figure 1*. If, for example, a capacitor of value 1 μF is used, the resistor value must be:

$$R = \frac{1}{2\pi \times 100 \times 1 \times 10^{-6}}$$
$$= 1591\ \Omega$$

to give us the network.

Other examples of Bode plots

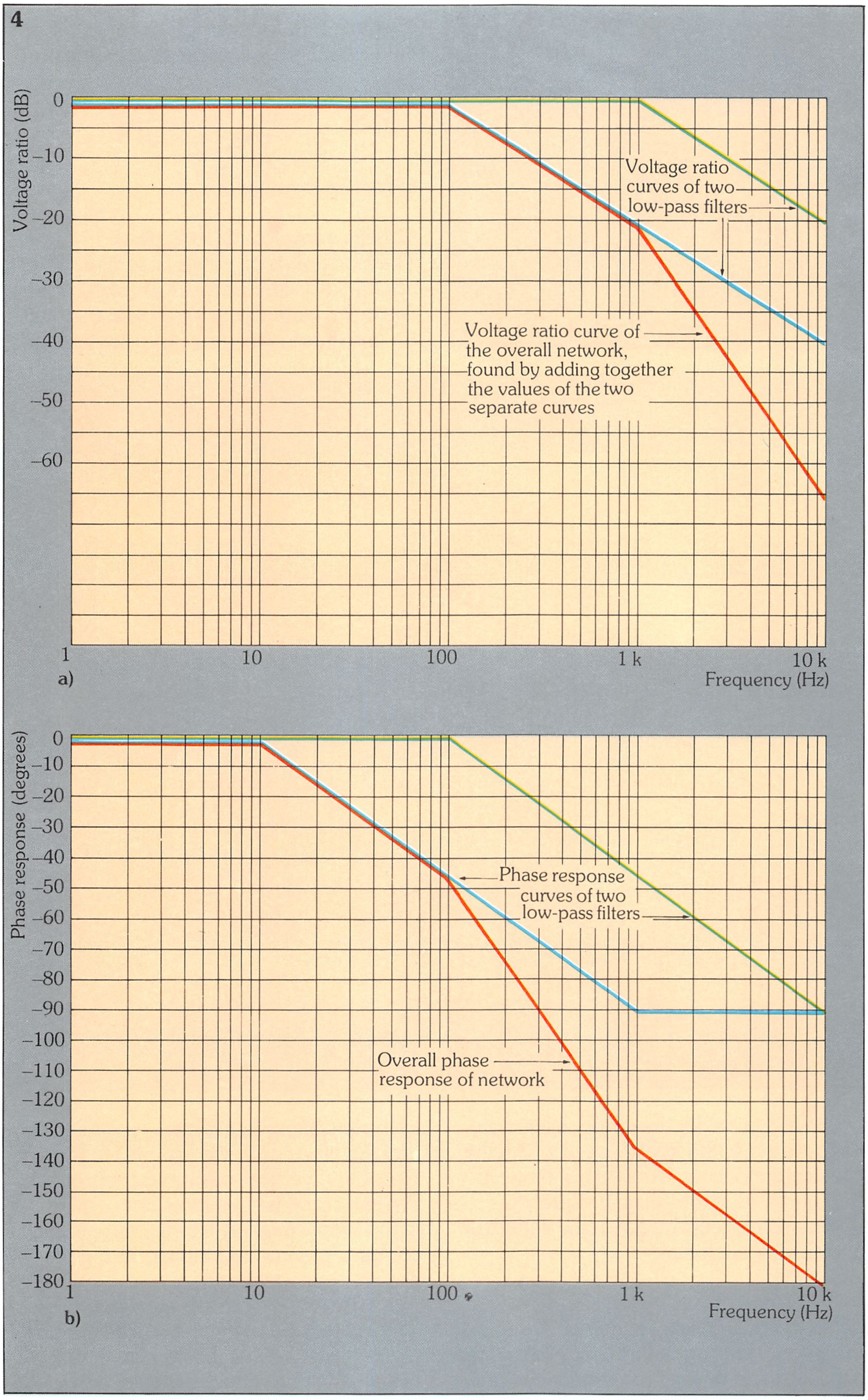
The Bode plots of a high-pass filter, resistor/capacitor network are shown in *figure 3a*. Note that both plots are shown on one graph – the red curve corresponds to the left-hand vertical axis (voltage ratio) and the blue curve corresponds to the right-hand vertical axis (phase response). We can combine two plots onto one graph in this way if they are simple, but more complex plots or combinations of plots require separate graphs.

The difference between *figures 1* and *3* illustrates one of the main uses of Bode plots – they provide a convenient method of showing differences between networks

Let's consider the corner frequency of *figure 1*, i.e. the frequency at which the break point occurs. It is 100 Hz. Now, it happens that at the corner frequency a relationship occurs between the capacitor and resistor such that:

$$CR = \frac{1}{2\pi f_c}$$

where f_c is the corner frequency. This means that we can define the values of the capacitor and resistor to produce the net-



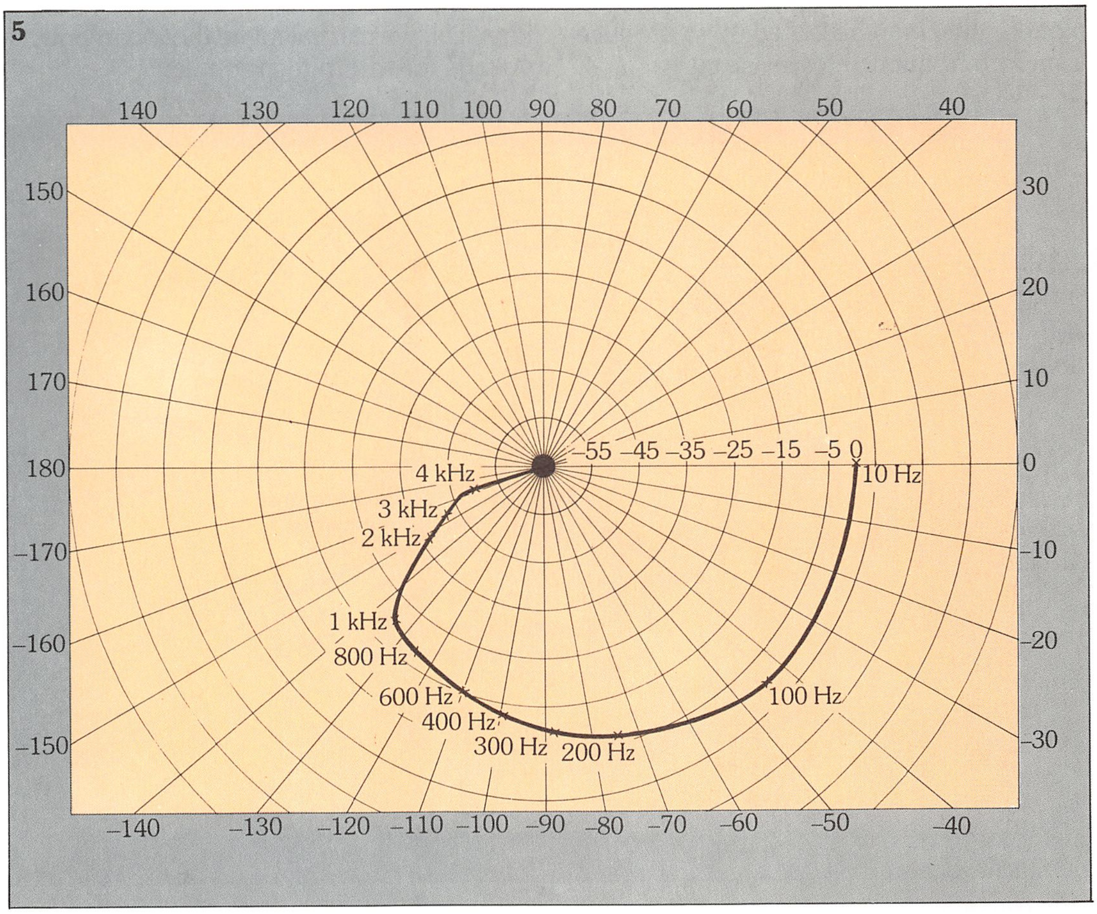
4. Bode plots for two low-pass filter networks (blue and green) added together to give the overall frequency response (red): **(a)** voltage ratio plot; **(b)** phase response plot.

and hence give an idea of how networks function. A Bode plot with the overall shape of *figure 1*, for example, will always represent the network of a low-pass filter.

Another important use of Bode plots is to calculate the frequency response of a network, if the network comprises a number of smaller networks whose frequency responses are known. For example, a network may consist of two low-pass filter networks in cascade and we may wish to know the overall frequency response. This can be done simply by adding the two Bode plots together. *Figures 4a* and *b* show the two plots of the two low-pass networks (we've used two separate graphs again): one in blue, one in green. The blue plots indicate that one low-pass filter has a corner frequency of 100 Hz, while the green plots tell us that the other low-pass filter has a corner frequency of 1 kHz. The overall frequency response, found by adding together the values of the blue and green plots at each frequency, is shown on the Bode plots in red.

We can see that the overall response is still that of a low-pass filter but it has a second corner frequency. Between the lower and upper corner frequencies the voltage ratio falls at a rate of 20 dB/decade, but above the upper corner frequencies the roll-off is 40 dB/decade. The total phase response is −180°.

In practice, this result would probably not occur because the first low-pass filter network would be loaded by the second low-pass filter network. The use of Bode plots is, however, an approximation anyway, so as long as we bear loading effects in mind, they can give adequate results.

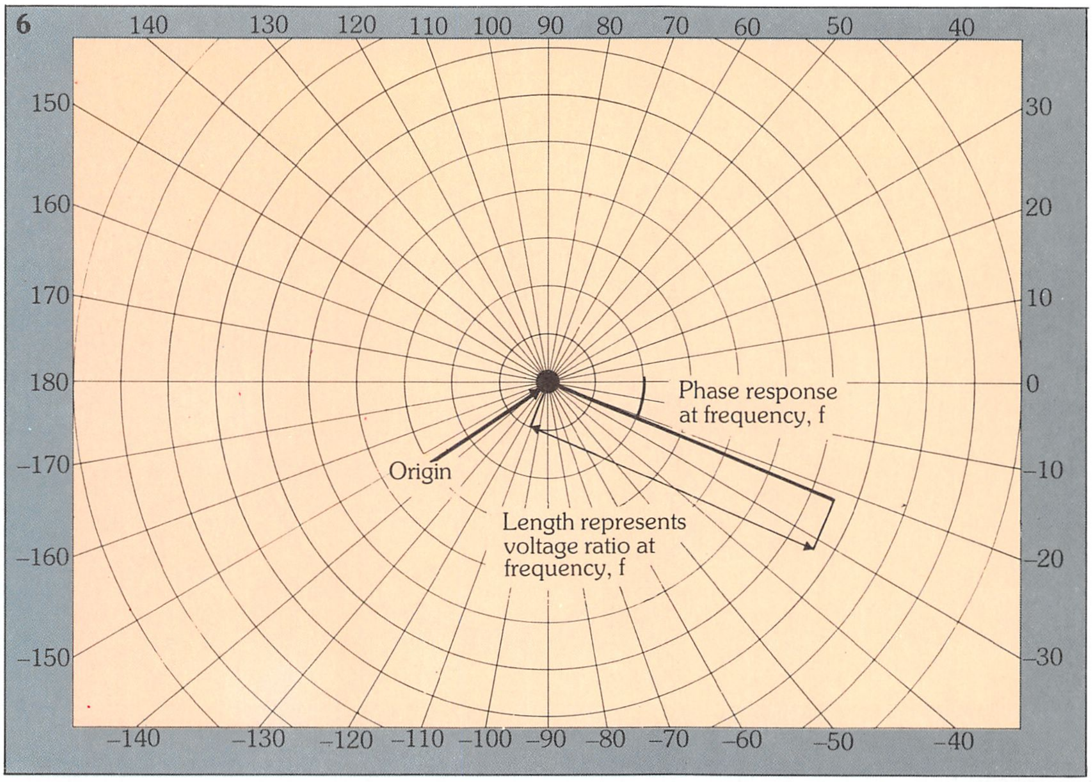


5. A Nyquist plot or harmonic response locus of the two low-pass filter networks whose Bode plots are shown in *figures 4a* and *4b*.

Another way to plot frequency response

Bode plots are used to create a two dimensional image of a network's frequency response. Other two-dimensional images are possible, and an example is shown in *figure 5* of a **Nyquist plot,** sometimes known as a **harmonic response locus.** The plot shown is that of the overall response, plotted in *figure 4*, of the

two series connected low-pass filters. At selected frequencies in the response, points are plotted on the harmonic response locus: at a distance from the origin which represents the voltage ratio; and an angle from the 0° axis corresponding to the phase response. *Figure 6* shows the method of plotting a single point on the harmonic response locus. After a representative number of points have been plotted, they may be joined up to produce a smooth frequency response curve.



6. Plotting a single point on a harmonic response locus.

Using decibels

The use of Bode plots when calculating the overall frequency response of a number of cascade connected networks illustrates that the voltage gain (in dB) at a particular frequency may be found by simply adding the individual voltage gains (in dB) of each network at that frequency. This is fairly obvious when we think about it, because the decibel is a logarithmic unit and their addition corresponds to the multiplication of the networks' non-logarithmic voltage gain. Let's look at an example to clarify how this works.

Let's say two networks are connected in cascade: one is an amplifier with a voltage gain of 10 (20 dB); the other is a filter with a voltage gain of 0.5 (−6 dB). By multiplication the non-logarithmic voltage gain is:

$$10 \times 0.5 = 5$$

and by addition, the logarithmic voltage ratio is:

$$20 + (-6) = 14 \text{ dB}$$

If we wish to confirm that these results are identical, we can calculate the logarithmic voltage ratio from the formula:

$$\text{voltage gain (dB)} = 20 \log_{10} \frac{V_o}{V_i}$$
$$= 20 \log_{10} 5$$
$$= 13.979$$

i.e. close enough!

Although it may seem more complex to use decibels rather than non-logarithmic voltage ratios, they do give important advantages, not the least of which is the fact that, with their use, frequency response may be shown on a Bode plot as a collection of straight line approximations.

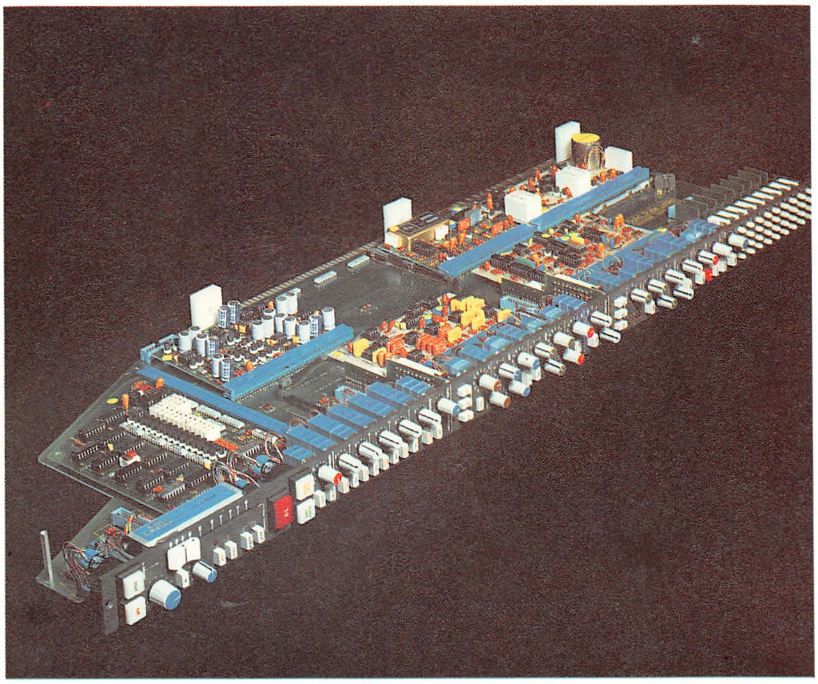
Table 1 gives a list of logarithmic and non-logarithmic voltage ratios. The central column lists a selection of decibels. To convert between a decibel figure and the corresponding non-logarithmic figure,

simply move from the central to the left column if the decibel figure is negative, or to the right column if the figure is positive. The voltage ratio figures are correct if the input and output resistances of the networks are the same.

Generally, the most used decibel figures and their corresponding non-logarithmic voltage ratios are:

$$0\text{ dB} = 1$$
$$3\text{ dB} = \sqrt{2} \approx 1.4$$
$$6\text{ dB} = 2$$
$$20\text{ dB} = 10$$
$$-3\text{ dB} = \frac{1}{\sqrt{2}} \approx 0.7$$
$$-6\text{ dB} = 0.5$$

Below: circuitry for one channel of a sound mixing desk. Frequency response analysis plays an important role in the design of such a system.



The Research House/Solid State Logic Ltd

Table 1
Logarithmic and non-logarithmic voltage ratios

Voltage ratio if – dB	Decibel figure	Voltage ratio if +dB
1.00	0	1.000
0.989	0.1	1.012
0.977	0.2	1.023
0.966	0.3	1.035
0.955	0.4	1.047
0.944	0.5	1.059
0.933	0.6	1.072
0.912	0.8	1.096
0.891	1.0	1.122
0.841	1.5	1.189
0.794	2.0	1.259
0.750	2.5	1.334
0.708	3.0	1.413
0.668	3.5	1.496
0.631	4.0	1.585
0.596	4.5	1.679
0.562	5.0	1.778
0.501	6.0	1.995
0.447	7.0	2.239
0.398	8.0	2.512
0.355	9.0	2.818
0.316	10	3.162
0.282	11	3.55
0.251	12	3.98
0.224	13	4.47
0.200	14	5.01
0.178	15	5.62
0.159	16	6.31
0.126	18	7.94
0.100	20	10.00
3.16×10^{-2}	30	3.16×10
10^{-2}	40	10^{2}
3.16×10^{-3}	50	3.16×10^{2}
10^{-3}	60	10^{3}
3.16×10^{-4}	70	3.16×10^{3}
10^{-4}	80	10^{4}
3.16×10^{-5}	90	3.16×10^{4}
10^{-5}	100	10^{5}
3.16×10^{-6}	110	3.16×10^{5}
10^{-6}	120	10^{6}

Glossary

corner point, break point, 3 dB point, roll-off point — point on an approximated Bode plot curve where two straight lines meet. The frequency at which a corner point occurs is therefore known as the corner frequency, f_c

harmonic response locus, Nyquist plot — an alternative method of showing frequency response of a network in a two-dimensional form

BASIC THEORY REFRESHER

ELECTRICAL TECHNOLOGY

Efficiency of transformers

We have seen in the previous *Basic Theory Refresher* that a certain fixed power is lost in a transformer regardless of the load current flowing in the secondary. This lost power is made up of the eddy current loss and the hysteresis loss, jointly known as the **iron loss**, P_{Fe}. In addition to this, the load current flowing through the transformer's windings also causes a loss of power, known as the **copper loss**, P_{Cu}, where:

$$P_{Cu} = I_2^2 R_2$$

R_2 is the resistance in the secondary winding, equivalent to the effect of the resistance of both primary and secondary coils. The copper loss is determined from a short circuit test, carried out at a reduced primary voltage.

The **efficiency** of a transformer (denoted by the greek letter eta, η) is defined as the ratio of the output power P_o to the input power P_i:

$$\eta = \frac{P_o}{P_i}$$

Now, the input power is equal to the output power plus losses:

$$P_i = P_o + P_{Cu} + P_{Fe}$$

Hence:

$$\eta = \frac{P_o}{P_o + P_{Cu} + P_{Fe}}$$

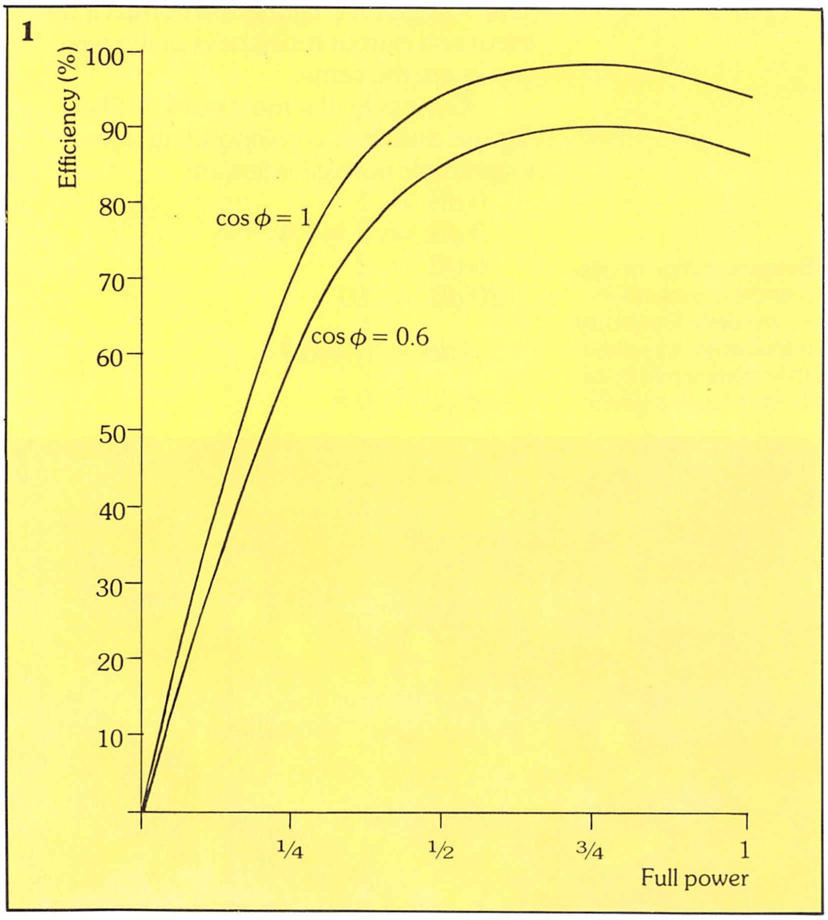
From this expression, the efficiency of a transformer working into a load of any magnitude and power factor can be determined.

We may now use this expression to calculate the efficiency of a 100 V, 500 VA transformer operating at ¾ full load current, with power factors: (a) of unity; and (b) of 0.2 lagging. An open circuit test on the transformer at 100 V consumed 10 W; a short circuit test in which the short circuit current was 5 A, consumed 25 W. Remember, a transformer's VA rating refers to the output apparent power. The full current load of the transformer is thus:

$$\frac{500}{100} = 5\text{ A}$$

a) Unity power factor:

Current	$= 3.75$ A
Output power	$= 100 \times 3.75$ $= 375$ W
Iron loss	$= 10$ W



1. The efficiency of a transformer varies with load current. Note how the lagging power factor gives an efficiency curve which rises to a lower maximum value.

$$\text{Copper loss at 3.75 A} = 25 \times \left(\frac{3.75}{5}\right)^2 = 14.1\text{ W}$$

$$\eta = \frac{375}{375 + 14.1 + 10} = 0.94$$

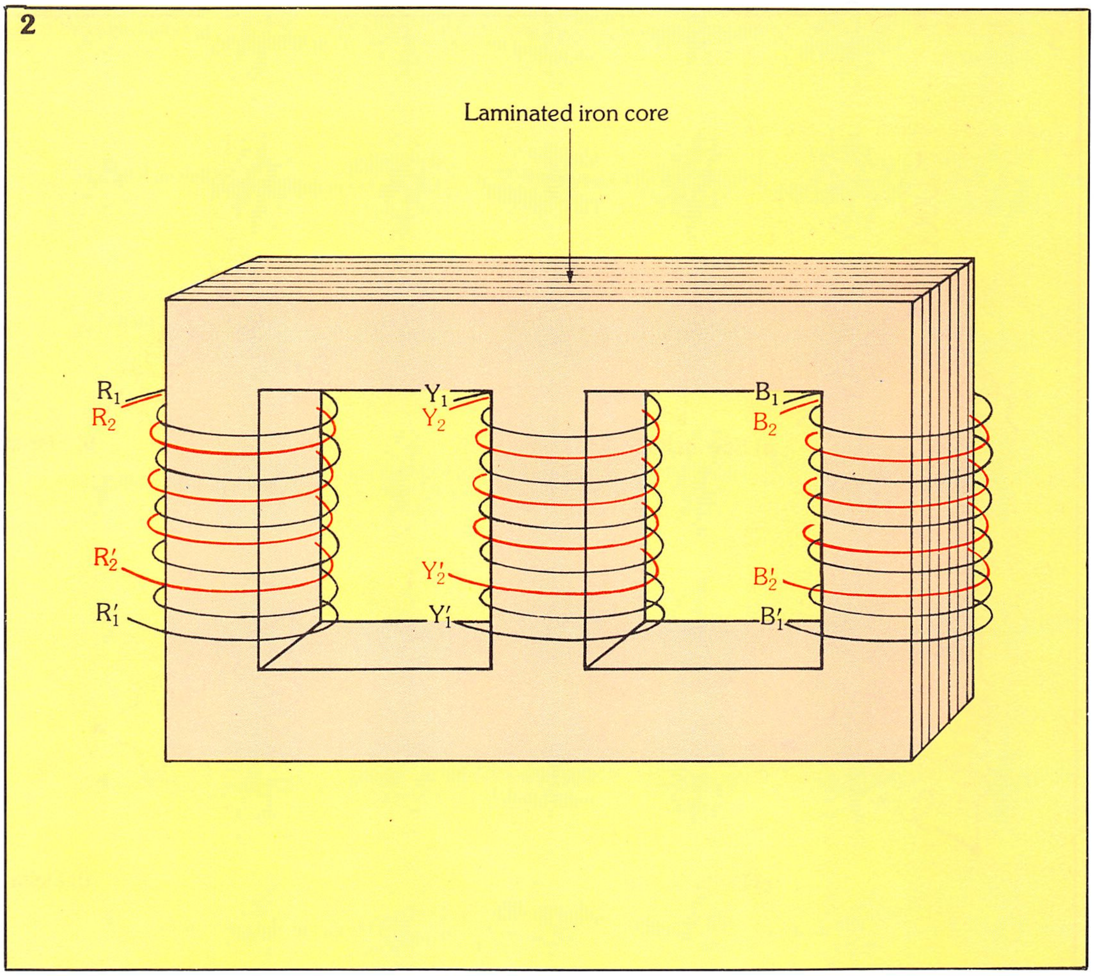
b) Power factor = 0.2

$$\text{Output power} = 375 \times 0.2 = 75\text{ W}$$

$$= \frac{75}{75 + 14.1 + 10} = 0.757$$

Figure 1 illustrates how the efficiency of a transformer varies with load current. We can see that the efficiency at unity power factor is maximum at about ¾ full load power.

This is intentional since, on average, the transformer is supplying about ¾ full load power most of the time. The efficiency is very low at low powers, but transformers are not usually used at these levels. The efficiency is



2. Construction of a three-phase transformer.

also lower for power factors other than unity, and this is an incentive for electricity consumers to improve their load's power factor.

Figure 1 also shows that a lagging power factor gives an efficiency curve of the same shape as that for unity power factor, but it rises to a *lower* maximum value at about ¾ full load.

Three-phase transformers

Three-phase transformers are constructed in a similar way to single-phase devices, except each phase has its own primary and secondary winding. These could be supplied by three single phase transformers, but it is more economical to put three pairs of windings on a single three limbed core (*figure 2*): hence using much less iron.

The primary and secondary windings can be separately connected in either star or delta, providing the four possible methods of connection shown in *figure 3*. These arrangements allow various voltages to be taken from a supply.

Assume that the supply is 11 kV (line to line voltage) and the transformers have a step-down ratio of 10:1. The **star-delta** connection (*figure 3a*) has a primary voltage of:

$$\frac{11{,}000}{\sqrt{3}} = 6351\ \text{V}$$

The voltage across the secondary windings, and hence the secondary line voltage, is:

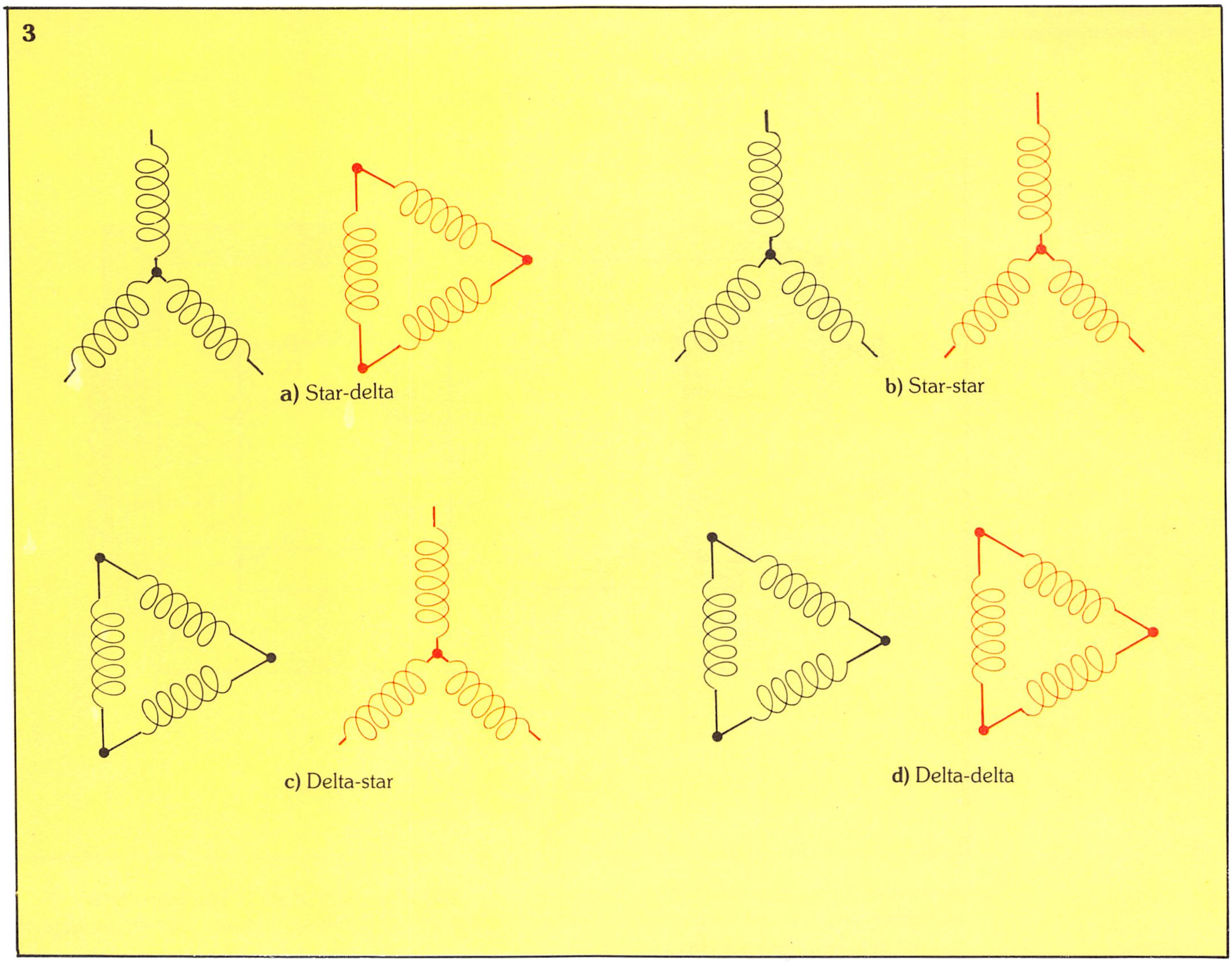
$$\frac{6351}{10} = 635.1\ \text{V}$$

In the **star-star** connection (*figure 3b*), the primary phase voltage is 6351 V as before, the secondary phase voltage is 635.1 V and the secondary line voltage is therefore:

$$\sqrt{3} \times 635.1 = 1100\ \text{V}$$

In the **delta-star** (*figure 3c*) connection, the secondary line voltage is 1905 V; in the **delta-delta** connection (*figure 3d*), it is 1100 V.

We can see that, depending on the way that the primary and secondary are connected, three different voltages can be obtained. The choice of connection also enables a star point to be obtained, so delta-star transformers are almost invariably used in the last stages of distributing electricity to consumers.



a) Star-delta

b) Star-star

c) Delta-star

d) Delta-delta

Autotransformers

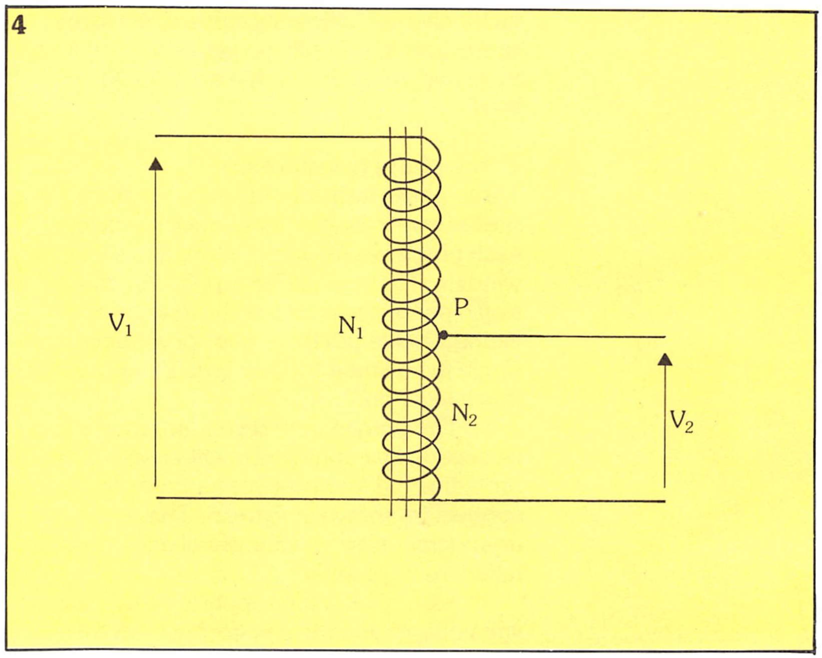
The **autotransformer** comprises a single winding on a laminated iron core, and is shown diagrammatically in *figure 4*. Autotransformers can be used to step-up voltages, but are more commonly employed as step-down devices. The secondary voltage is variable, and is altered by moving the secondary connection point up or down the coil. As in a normal transformer, the voltage ratio is given by:

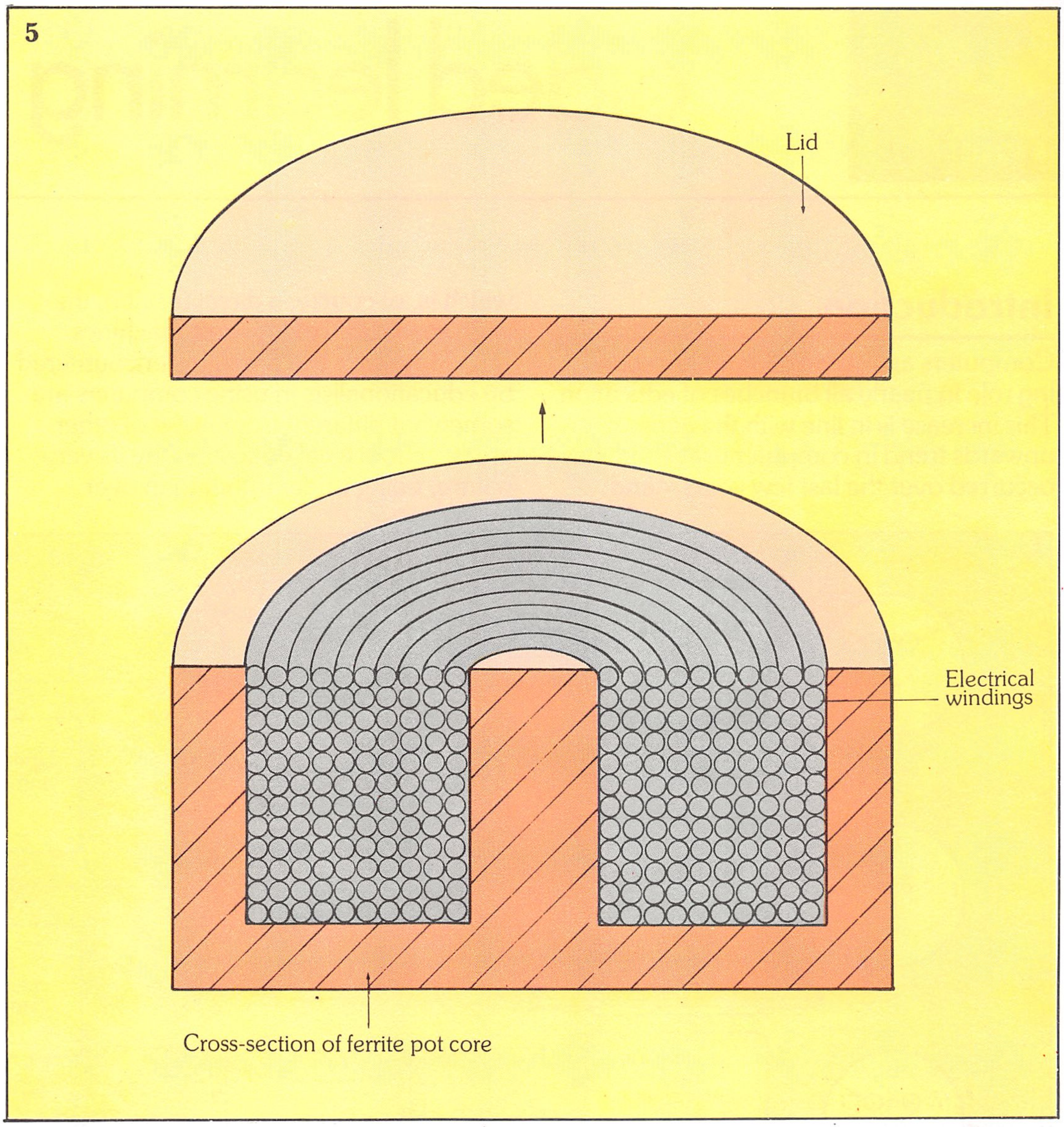
$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

However, unlike a normal transformer, the primary and secondary are not separate, and this means that a user would not be isolated from the mains. These devices are often made so that the secondary connection slides up and down the winding to provide a fully variable transformer, called **variacs**.

Audio transformers

Transformers that are used at audio



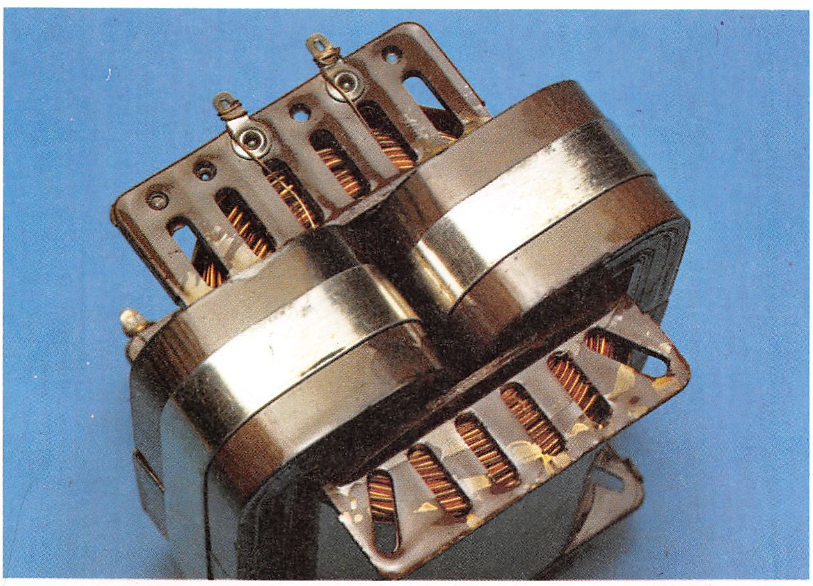


3. Possible methods of connection of the primary and secondary windings in a three-phase transformer.

4. An autotransformer.

5. Cross-section through an audio transformer.

Below: a single-phase step-down transformer.



frequencies are constructed in much the same way as mains frequency devices. The laminations, however, have to be much thinner because eddy current losses in a lamination increase with frequency and decrease with the thickness of the lamination. Often, a ferrite core material is used in such audio transformers because the electrical resistivity of ferrite is very high, and so the possibility of eddy currents is considerably reduced. These are often made in the form of a **pot-core** – shown in *figure 5*.

As you can see, the coils are totally enclosed in a pot of ferrite material. □

COMPUTERS & SOCIETY

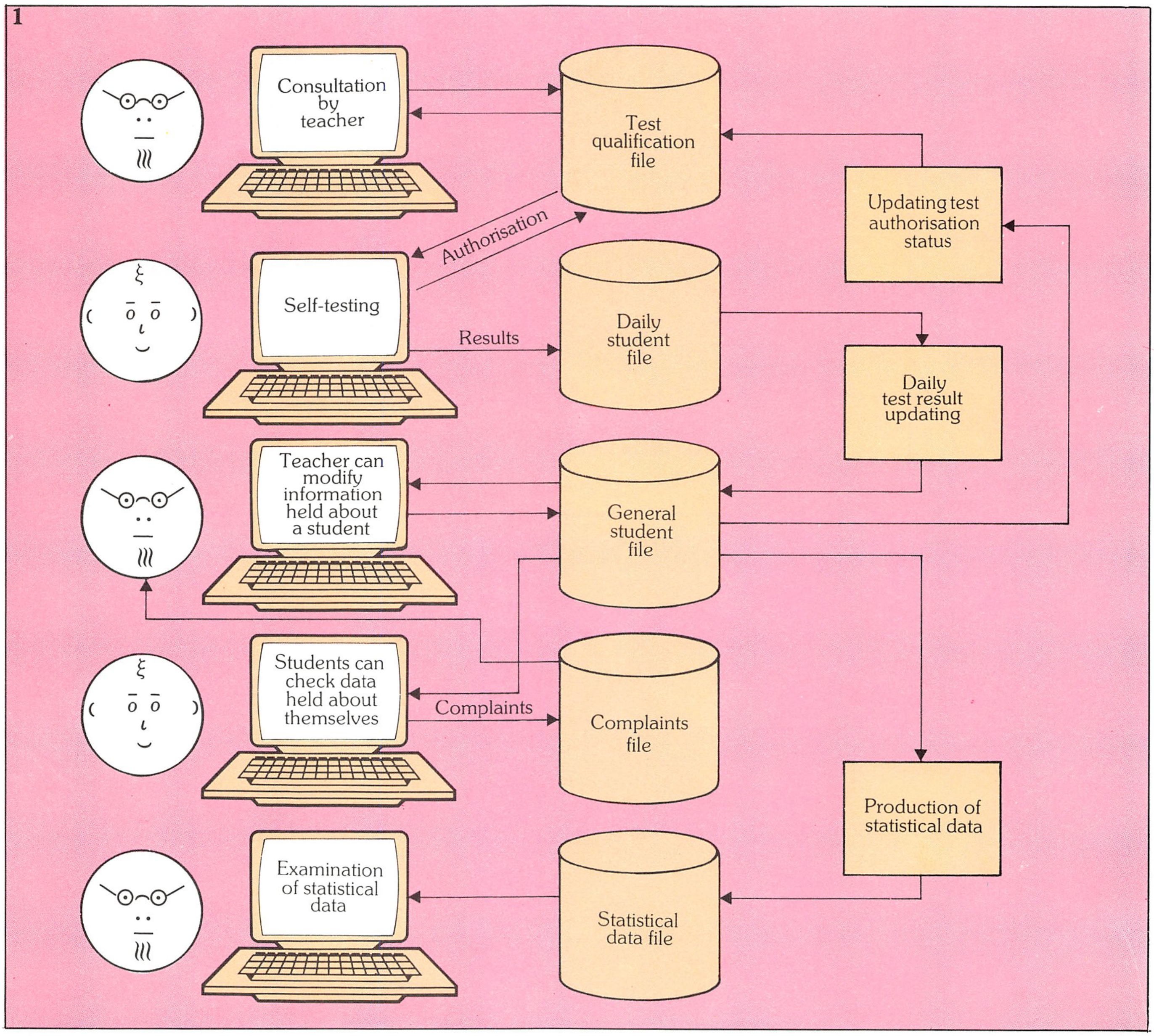
Computer aided learning

Introduction

Computers are playing a rapidly expanding role in nearly all branches of education. This increase is in line with the general upwards trend in computer usage that has occurred over the last few years – and which is, of course, a direct result of the wide availability of low-cost machines.

However, the problems encountered by educationalists in using computers are somewhat different from those of other areas; school level education, by its very nature, being under rather than over

1. The operation of the 'Introduction to Physics' course used by the University of California, Irvine.



funded. So, although the microcomputer boom has provided hardware for schools, there is not yet a market large enough to encourage the production of high quality software, resulting in the fact that some of the software packages used in schools are less well designed than they should be. However, recent moves, such as the involvement of the BBC in the promotion of a standard microcomputer, and the distribution of some software via radio, has done much to enhance the future development of the field.

Computers can fulfil several distinct roles in education: the main division being between those applications where special programs are used to present a teaching topic in a particular way; and those where computers are used 'vocationally' to teach programming and computer usage to students. The vocational use of computers is of growing importance in the higher reaches of the educational ladder, but most of our discussion here will focus on the use of computers as a teaching device – an advanced type of audio-visual aid.

An example of a computer assisted learning course is shown in *figure 1*: it is the 'Introduction to Physics' course used by the University of California, Irvine. Learning is regulated by each student according to their individual requirements; each can choose which subject module to study and the speed at which they progress. The rate and standard of learning is assessed by self-testing which is managed by the computer; as a student may need to be tested several times on a particular module, various tests must be available on the same subject material.

As can be seen from *figure 1*, the system contains five files:
1) Test qualification file: this contains information regarding which tests students are qualified to do at various stages in their course of study. It is automatically updated on the basis of results in the general student file and it monitors the dates that tests are taken – a minimum period is allowed between two successive tests. The file can also be consulted and altered, where necessary, by the instructor.
2) Daily student file: which contains the tests and results performed by each student on a daily basis.
3) General student file: this contains all data relating to student progress and is automatically updated with test results each day from the daily student file.
4) Complaints file: this contains complaints by students who have consulted their own files and found discrepancies.
5) Statistical data file: this file is produced by statistical analysis programs, providing such things as student and class profiles.

As you can see, controlling such a system is a very complex task.

Computer managed learning systems such as this are particularly appropriate for non-traditional concepts of schooling, for example, where all of the 'class' does not need to be present at the same time. It also relieves the teacher to spend more time helping those students with particular difficulties.

Political pressure on governmental and local authority spending in education has led many to espouse computer based learning techniques because they provide 'computer consciousness', which is seen to be an important educational aspect in our rapidly computerised world. Whether or not this is a cost effective exercise has not yet been clearly answered, but, in common with all teaching methods, if the material is both good and well presented then it is a valuable and worthwhile experience for the student – and if it is bad the converse is true. The advantages of computer based learning do not perhaps lie in the 'automation' of the learning process, but in the fact that the computer permits the student to experience activities which would otherwise only be discussed or read about.

There is also considerable, sometimes heated, debate about the level of computing knowledge and skills needed for a teacher to make effective use of computer-based learning in the classroom, and the level needed for him to assist in the development of new material. At present, educationalists probably have too little experience of the problem to effectively answer these questions.

As with all innovations that alter accepted methods, it is the *way* that computers are introduced into schools that will have a profound influence upon their acceptability as a teaching tool by both teachers and students alike.

The pre-microcomputer era

Universities and polytechnics have always been in possession of 'computing power', used in most cases to teach computer languages and to provide support for problem solving (where students use their programming skills to write programs which solve problems set in other parts of their course). The computer system was also a major resource for research groups, working either in computer science or applications areas. This requirement imposed a need for a flexible system of general applicability, and for this reason educational computer centres have been in the vanguard of the development of general purpose systems.

As we have said, most university usage is vocational, in the sense that the students are learning to use general computer systems and languages. Only a few universities have used their systems to develop teaching aids to present subjects unrelated to computers or their use. One of the most notable examples of this is the computer managed learning system, PLATO, developed at the University of Illinois. The PLATO system runs on CDC (Control Data Corp.) mainframe computers and comprises a complete suite of support tools and lesson material.

The system uses specially customised monochrome graphics hardware to present material to students. 'Lessons' are displayed using a combination of both text and pictures, providing considerable scope for the 'teacher' or lesson designer. Tutorial material is presented to the student, who works unsupervised, in a variety of ways; students have the flexibility of re-reading earlier lesson material to recap before continuing, or skipping over material they already know. Each student works interactively with the machine, answering questions and receiving answers.

One of its major innovations has been the production of the PLATO lesson-programming language which enables the tutor to encode the text for display, together with graphics patterns, in a programming language like script, consisting mainly of read and write type statements. The language also allows the lesson designer to control the many parameters that determine the way that the student works through the material.

Because the system is **computer managed**, the computer marks the answers which the student gives, and records them. In this way, the tutor is able to control the way in which the student progresses through the material by preventing advancement to the next unit until a certain minimum mark level has been attained. On-line help can be obtained conversationally if the relevant tutor is logged onto the system.

The system and its use have been developed over a period of two or so decades – a vast library of lesson material has now built up which is constantly revised. Students are required to use the system as part of their degree course work, and the marks which the computer records are used by the university as part of its grading system. Security, therefore, poses a major problem for the system managers – it must not be possible for students to alter their marks!

PLATO is one of the largest, most highly developed, and most integrated computer aided learning systems in the world. The problem with it is that it was designed some time ago, and therefore runs on mainframe computers which are far beyond the resources of all schools, most education authorities, and some universities. In such a system, hardware costs are extremely high. The graphics terminals used, for example, are specially modified. Communications costs are also high and are not considered as capital expenditure but must be found from the annual budget. In fact, the system suffers from all of the problems of large centralised computing facilities. Illinois and CDC are now working on the development of a workstation version of the system, which would either be networked to some central site, or would receive lesson updates through post or electronic mail.

Education authorities in the U.K. usually either possess or have access to computers which are used for record keeping, accounting, etc. Over a period of time, the spare capacity of these systems was shared out between those schools

which had terminals on-line to the system. These terminals were used to enter information about pupils, budgets, etc. and, after these requirements were met, any remaining capacity was used for teaching. Authorities also invested in computer managed learning systems of the PLATO type, which enabled students to study subjects such as maths or careers information.

The Open University, which assists many thousands of people in the U.K. to achieve degree qualifications though home-based learning correspondence courses, maintains a computing service for students. The service provides practical time-shared computing facilities using mainframe computers (Hewlett-Packard 2000 and DECSYSTEM-20 computers) via telephone links to students' local study centres. Often simply a room in a nearby school, study centres around the country are equipped with a teletypewriter terminal, modem and telephone.

Microcomputers and schools

Microcomputers have dramatically altered both primary and higher education classroom computing. There are now only a very few schools in the U.K. that do not have at least one micro. Many have several and considerable effort has been expended in making these machines an integral part of the teaching system. Due to the lack of suitable software, many teachers have found themselves writing their own programs. However, many do not have the computer skills required and training is therefore necessary – for this reason there have been national schemes to teach 'computer consciousness'.

One of these, known as the National Development Programme for Computer Aided Learning (NDPCAL), ran between 1973 and 1977 and is widely considered to

Right: PLATO terminal. (Photo: Control Data Corp).

have been a success.

The scheme was funded with up to two million pounds and its projects consisted largely of writing **demonstrator** programs – programs written by experts to demonstrate exactly what makes a 'good' program. Currently running is the Microelectronic Education Program (MEP) which has a short-term selection of courses for key teachers and advisors and is also concerned with the longer term development of curricula and resources.

The most important factor in the success of computer aided learning material is the availability of good quality software which is well documented and comes complete with a package of user notes and teachers' guides. As this is both expensive and difficult to achieve, software companies have been reluctant to commit expertise to the problem, especially when the market is not yet large. There is, unfortunately, no shortage of poor quality, badly researched packages available! On the other hand, there is a long standing misconception amongst those people not involved in the computing business that software can be given away free. This stems from the early days of computing when most of the development expenditure on a system went into the hardware – nowadays the reverse is true.

Software piracy is also a problem and hence the licensing arrangements for good educational software are usually very tight, resulting in expensive packages. There have been moves in the U.K. to set up a central purchasing agency to buy software and distribute it to schools, however, this has not yet happened.

Another area which is causing concern is the question of how much programming teaching should be done in schools. It has been claimed by the universities that people who have either learnt BASIC at home or at school need retraining in order to progress. This could be the result of a problem with the language itself – if PASCAL, a structured language, was available on microcomputers and taught in schools instead of BASIC, rather more discipline would be instilled into students' computing skills. However, this highlights a more significant problem with the subject area. Although the discipline of computer programming changes very little, languages come in and go out of fashion, new techniques are developed etc., and it is easy for those not directly involved in the field on a full-time basis to lose touch. Education systems, by their very nature, respond very slowly to change so the question of 'what to teach and how much' demands serious consideration.

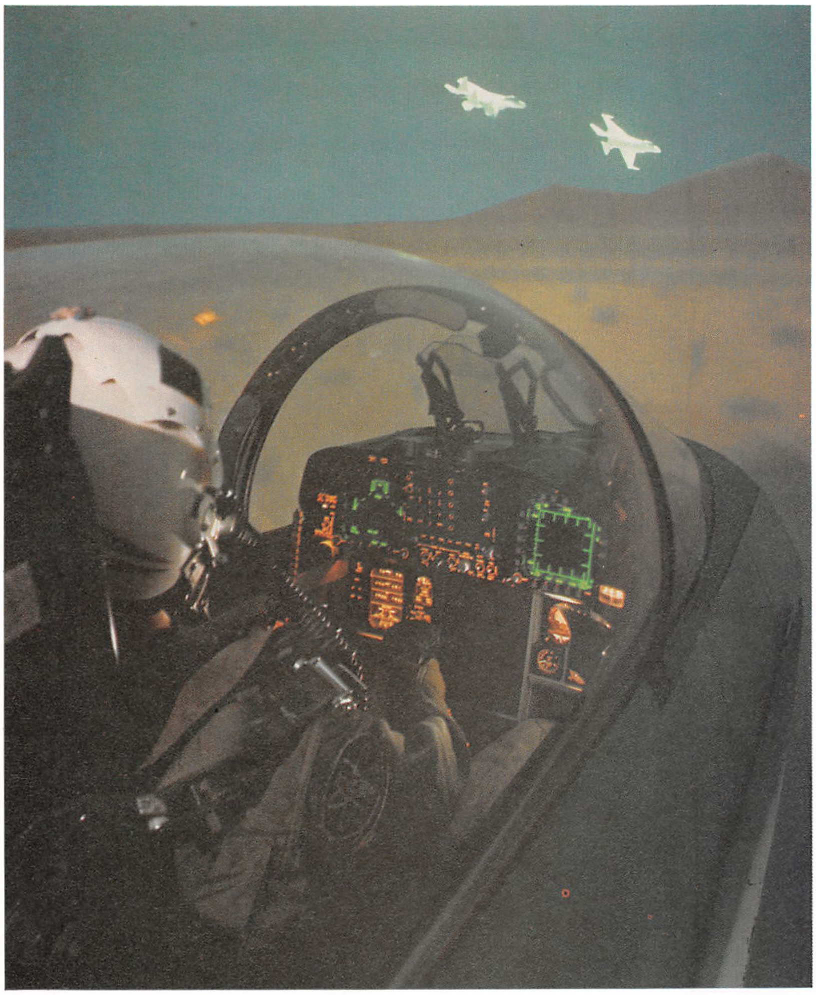
Types of application

Computers can be used to deliver instruction in a variety of ways, the most common of which is the **drill and practise** application. This does not require the teaching of new material and is therefore generally inexpensive. The software simply presents examples of already delineated problems and checks that the student's response agrees with the predetermined (correct) answers.

Although varying levels of sophistication exist in educational software, drill and practise programs can be easily written by most teachers who have a little programming knowledge.

The program designer determines the style and frequency of student performance reports. This may range from a simple report of the number of correct answers at the conclusion of the session, or the program may indicate whether an answer is right or wrong immediately after the response. The style of the report is usually intended to reinforce the quality of the answers with some reward or penalty and some systems offer a variable grading which can be altered by the user. The style of reporting also varies according to the target audience: for the young child this might be colour and movement; on the other hand, an undergraduate would probably prefer a simple report of the number of right and wrong answers.

The program should also include a facility to increase the difficulty of the questions asked throughout the session, or even better, employ a variable rate of increase so that a bright student can skip over simple questions and advance to the next level of difficulty. Some individuals prefer to achieve to a certain level and stay at that level for a while – this gives them a boost before advancing to the next level. In this case, the program should be able to slow the rate of increase in difficulty on



The Research House/Hughes Aircraft Company

Above: comprehensive combat training is provided without leaving the ground by this flight simulator. The 360° image of the sky, ground and targets is computer generated as are the instrument panel displays.

demand, enabling the student to work through many examples.

Although not the most interesting aspect of education, drill and practise is a necessary mode of learning and the hope must be that computer methods make it more attractive, through the use of inventive and enjoyable techniques, thereby encouraging students to demonstrate their factual knowledge and thus gain greater educational benefit.

Tutorials

Sometimes **tutorials** are integrated with drill and practise sessions, and students are then given new material, rather than merely examples to be answered. The program may either be entirely self-contained, or it may have supplementary notes, or be designed to back-up other material.

A less well developed area of educational computing which spreads across drill and practise and tutorials, is the **tutoring technique**, in which the program provides helpful hints and reminders as the student proceeds. Programs are designed, for example, to query an answer given by a student. Designing programs like this, however, is extremely difficult as there are usually different ways to solve a given problem and it is difficult to decide on the appropriate time to intervene.

Instruction support

Instruction support consists mainly of tools which are provided as a part of other programs. Automatic testing and record keeping, for example, are sometimes combined with tutorials and drill and practise programs. These services can also be used in non-computer based learning systems, since the records generated can be easily transferred to a computer system. This process is really computer *managed* instruction. The PLATO system mentioned earlier can, for example, report on whether a student has completed a particular course, and can then restrict the student from other courses until a set of prerequisites has been completed. These systems have proved to be cost effective in those content areas where the material is clearly delineated, and in educational environments where individualised learning and self-paced progress is helpful.

Support tools can be used in other areas, such as laboratories, where measurements need to be taken and data is to be analysed and reports produced. In mathematics classes they can graph functions, or perform calculations and statistical analyses.

If support programs have database facilities, then they can be used as information storage and retrieval systems, for example by local education authorities for careers advice and information.

Word processing has been investigated as a teaching aid in the composition of written work. Some psychologists expect that the rate at which writing skills are acquired will increase with the use of word processors. Some children say that the freedom to make mistakes and to know that they are correctable without the teacher ever seeing them is the best thing about computers: the delete button is the most user-friendly part of the machine!

Simulations

It is probably well known that computers are frequently used to simulate hypothetical situations to investigate cause and effect relationships, and to provide forecasts of such things as population growth, food requirements and so on. This facility of simulation can be used to good effect in education, providing students with a means of testing their ideas on a model of the real world. Simulations also allow the environment to be simplified, and this means that basic problem solving techniques can be mastered before a student progresses to more complex systems.

Simulations have long been used in the social sciences, for example role playing in business studies and sociology. This technique of simulation, however, is probably at its most useful in higher education – there is still no substitute for real experience wherever this is possible, particularly for younger students.

Simulations in biology

The construction of biological models is difficult because the behaviour of the modelled systems is extremely complex, and often not fully understood. At school level, simulations are being used in the teaching of such areas as enzyme kinetics, genetics, evolution, population dynamics and some physiological processes.

As an example, we'll look at the simulation of the ecology of a pond. Using this, the student is able to study the interaction of trophic (feeding) levels in a pond and some of the effects of outside interference from man. Four types of investigation can take place:

1) observations of the populations in the pond ecosystem under stable conditions;
2) population effects of varying the initial populations of the separate trophic levels;
3) the effect on population of catching fish, and the effect of having a closed fishing season;
4) the effect of polluting the pond with undesirable chemicals.

Figure 2 illustrates a session with the program. The student's responses are printed in the heavier type, so that the interaction with the system can be seen more clearly.

2

a)

```
WHICH STAGE DO YOU WANT (TYPE 0 FOR A LIST) ? 0
   YOU CAN
 1  CATCH FISH
 2  SET INITIAL NUMBERS OF PHYTOPLANKTON, HERBIVORES & FISH
 3  POLLUTE THE POND
** TYPE 1 2 OR 3 ? 2

WHAT ARE THE INITIAL NUMBERS OF
  PHYTOPLANKTON (0–250) ? 150
  HERBIVORES (0–50) ? 25
  FISH (0–1000) ? 700
```

b)

```
YEAR  PHYTOPLANKTON             HERBIVORES               FISH
  1   (THOU.MILLIONS)           (MILLIONS)          (ACTUAL NUMBERS)
      0   100  200  300   0    20   40   60   0   1000 2000 3000 4000
      +....+....+....+....+....+....+....+....+....+....+....+....+
JA    .          P        .      H            . F                 .
FE    .              P    .         H         . F                 .
MA    .               P   .           H       . F                 .
AP    .              P    .   79 MILLION      .     F             .
MY    .            P      .              H    .               F   .
JN    .            P      .               H   .          F        .
JL    .                 P .              H    .          F        .
AU    .          P        .              H    .      F            .
SE    .         P         .          H        .     F             .
OC    .         P         .           H       .    F              .
NO    .         P         .       H           .    F              .
DE    .     P             .     H             .    F              .
ANOTHER YEAR ? YES
```

c)

```
YEAR  PHYTOPLANKTON             HERBIVORES               FISH
  2   (THOU.MILLIONS)           (MILLIONS)          (ACTUAL NUMBERS)
      0   100  200  300   0    20   40   60   0   1000 2000 3000 4000
      +....+....+....+....+....+....+....+....+....+....+....+....+
YEAR 2
JA    .        P          .        H          .   F               .
FE    .           P       .          H        .   F               .
MA    .                 P .            H      .   F               .
AP    .                 P .             H     .          F        .
MY    .                P  .                  H.               F   .
JN    .               P   .                H  .             F     .
JL    .            P      .          H        .           F       .
AU    .            P      .                H  .          F        .
SE    .            P      .          H        .          F        .
OC    .           P       .          H        .     F             .
NO    .        P          .        H          .      F            .
DE    .     P             .      H            .     F             .
ANOTHER YEAR ? NO
```

3

a)

WHAT IS TO VARY
1 TEMPERATURE
2 INITIAL AMOUNTS OF S02 and 02
3 PRESSURE
1

WHAT ARE THE INITIAL AMOUNTS OF S02 & 02 (MOLES)
(TYPE BOTH VALUES SEPARATED BY A COMMA) ? **2,1**
WHAT IS CONSTANT PRESSURE (ATM) ? **50**
DO YOU WANT TO USE A CATALYST ? **NO**

TYPE VALUES OF TEMPERATURE IN THE TABLE WITH –1 TO END

TEMPERATURE (DEG C)	EQUILIBRIUM AMOUNTS SULPHUR DIOXIDE	OXYGEN	SULPHUR TRIOXIDE
150	–	–	2.0000
250	–	–	2.0000
500	.0657	.0328	1.8300
750	.6720	.3360	1.3200
1000	1.5300	.7660	.4670
1250	1.3300	.9190	.1600
–1			

DO YOU WANT TO USE THE PROGRAM AGAIN ? **YES**
WHICH PART ? **1**

b)

WHAT IS TO VARY
1 TEMPERATURE
2 INITIAL AMOUNTS OF S02 and 02
3 PRESSURE
1

WHAT ARE THE INITIAL AMOUNTS OF S02 & 02 (MOLES)
(TYPE BOTH VALUES SEPARATED BY A COMMA) ? **2,1**
WHAT IS CONSTANT PRESSURE (ATM) ? **50**
DO YOU WANT TO USE A CATALYST ? **YES**

TYPE VALUES OF TEMPERATURE IN THE TABLE WITH – 1 TO END

TEMPERATURE (DEG C)	EQUILIBRIUM AMOUNTS SULPHUR DIOXIDE	OXYGEN	SULPHUR TRIOXIDE
150	0	0	2.0000
250	0	0	2.0000
500	.0657	.0328	1.9300
750	.6720	.3360	1.3200
1000	1.5300	.7660	.4670
1250	1.3300	.9190	.1600
–1			

DO YOU WANT TO USE THE PROGRAM AGAIN ? **NO**

2. Simulation of the ecology of a pond as an example of computer assisted learning.

3. Computer simulation of part of the Contact process demonstrating the effect of a catalyst.

This example shows how the technique of simulation can extend the subject range of students. Although some elementary laboratory study of pond population dynamics is possible, the wide range of species interactions can only be properly studied in the field. However, such activities are time consuming and it might not be possible for field studies to coincide with, say the breeding cycle of a fish! A second consideration is that the field study can only ascertain what is happening in the ecosystem at that time. Determining the effects of environmental change are not possible – for example, the effects of drought or pollution could not be studied. In these instances, a computer simulation provides an invaluable learning tool.

Industrial processes

Programs have been developed to simulate the Haber process for the production of ammonia and the Contact process for the production of sulphuric acid. Simulations such as this enable students to investigate the optimal conditions under which a process must be carried out, and also to determine what might happen should a particular parameter in the process be altered.

Students also gain some appreciation of the compromises which have to be introduced into most real life systems: there is usually some conflict between chemical principles on the one hand, and economic or technological constraints on the other.

The best demonstration of this is to examine a sample output as shown in *figure 3*. This demonstration forms part of the Contact process and shows the effect of temperature and the introduction of a catalyst upon the yield of sulphur trioxide during the process. (Again the student's responses are shown in the heavier type.) These simulations allow students to determine the operating conditions for temperature and pressure in order to produce a high yield of sulphur trioxide. In this example, the catalyst has a neglible effect upon the yield; from previous experience, students will be aware that the higher the operating temperature, the higher the rate of reaction, so although increasing the temperature reduces the yield, it results in the formation of the sulphur trioxide more rapidly. The problem, therefore, is to determine the temperature and pressure at which the increase in reaction rate is offset by the declining yield.

The problem can be taken a stage further as shown in *figure 4*, where additional constraints are applied to the process. The sulphur trioxide must be produced at an economical rate, while the process must be operated at a yield high enough to ensure that the plant will not be closed for environmental reasons. The exercise can be enhanced by several groups of students working in competition:

the price of the sulphur trioxide as their trading parameter. Such simulations permit a much more practical understanding to be developed than is ever possible from reading a textbook or by a teacher explaining the problems.

Physics

In the examples that we have just looked at, the model on which the simulation is based is unseen, the computer does the work and decides upon the answers. However, in some subjects it is the model itself which is being taught. In schools the examination of models is often limited either to qualitative discussion or a simple quantitative treatment involving a few simple calculations. This approach is understandable, because the calculations are often complex, and to perform a sufficient number of them to explore the model in detail would consume far too much time and energy.

A computer, however, can enable quantitative exploration of such models to be carried out rapidly and in very fine detail. The student is thus released from the chore of performing the calculations, a task which can obscure the objectives of the whole exercise. The computer based approach can also allow the comparison of different models, and the further development of a model to account for some other piece of evidence. The model can be made sufficiently comprehensive that when a student feeds in experimental data the computer can respond with evidence relating that data to known laws of physics.

Economics

Models of the economy are used at the Treasury to predict the behaviour of the pound, interest rates and the money supply under various policies which might be pursued by governments. The simulations used in schools are not as sophisticated, of course, but do permit the behaviour of a very large, complex system to be examined under various situations.
It is usually impossible to perform the simulation of systems like these without computer aid, because of the extreme complexity of the calculations, and the number of times they must be performed.

4

a)

```
WHAT IS TEMPERATURE (DEG C) ? 500
WHAT IS THE INITIAL MOLAR RATIO S02:02
  (TYPE TWO NUMBERS SEPARATED BY A COMMA) ? 2,1
WHAT IS PRESSURE (ATM) ? 50
DO YOU WANT TO USE THE CATALYST ? YES
MAXIMUM POSSIBLE CONVERSION OF S02 IS 96.7%
USING ONE CONVERTER 4513 TONNES
OF SULPHURIC ACID IS PRODUCED PER DAY.
COSTS PER DAY (TO NEAREST POUND)
MANPOWER          :      300
CATALYST          :       15
PLANT/REPAIRS     :  6.2E+09
SULPHUR DIOXIDE   :    45714
STEAM CREDIT      :    -9451
ELECTRICITY       :   368573
WATER             :     1354
                  -----------
TOTAL             :  6.2E+09
COST PER TONNE - 1.37E+06 POUNDS
***** POLLUTION - PLANT CLOSED BECAUSE
      MORE THAN 1% OF S02 UNCONVERTED
DO YOU WANT TO USE THE PROGRAM AGAIN ? YES
```

b)

```
WHAT IS TEMPERATURE (DEG C) ? 427
WHAT IS THE INITIAL MOLAR RATIO S02:02
  (TYPE TWO NUMBERS SEPARATED BY A COMMA) ? 1,1
WHAT IS PRESSURE (ATM) ? 1.5
DO YOU WANT TO USE THE CATALYST ? YES
MAXIMUM POSSIBLE CONVERSION OF S02 IS 99.1%
USING ONE CONVERTER 350 TONNES
OF SULPHURIC ACID IS PRODUCED PER DAY.
COSTS PER DAY (TO NEAREST POUND)
MANPOWER          :      300
CATALYST          :       15
PLANT/REPAIRS     :      590
SULPHUR DIOXIDE   :     3463
STEAM CREDIT      :     -840
ELECTRICITY       :      292
WATER             :      105
                  -----------
TOTAL             :     3925
COST PER TONNE - 11.19 POUNDS
DO YOU WANT TO USE THE PROGRAM AGAIN ? NO
```

Figure 5 illustrates a typical example in which the student is assigned the role of Chancellor of the Exchequer. The rather simplified model is controlled by adjusting government spending and taxation. The program offers the chance to gain experience of analysing an economic situation, attempting the changes which should effect the target variables, selecting priorities for action, and analysing the conflicts between political and economic expediency.

Geography

Recently, there has been a trend in sixth form geography to include quantitative aspects of the subject in the syllabus. This has resulted in teachers investigating the

4. Using a simulation to determine the cost per tonne of Sulphuric Acid produced under different conditions.

5. Economic modelling.

5

a)

```
YEAR 1 : ECONOMY BOOMING

RATE OF TAX = 30
PLANNED GOVT SPENDING = 4673

POTENTIAL       = 24000     (I = 4592 S = 4150)
ACTUAL          = 23572     (C = 9987)
GROWTH          = 1.1%
UNEMPLOYMENT    =  505 M
PRICES          = 107
B-OF-P          = -550      (X = 4144 M = 4664)
RESERVES        = 60
NAT DEBT        = 8107      (G = 4878 T = 4771)
                  (+ 107)
OPINION POLL    = 56%

(TO END PROGRAM TYPE -1 FOR RATE OF TAX)
```

b)

```
YEAR 2

RATE OF TAX ? 35
PLANNED GOVT SPENDING ? 5200

POTENTIAL       = 24998     (I = 5301 S = 4127)
ACTUAL          = 23250     (C = 8709)
GROWTH          = -1.4%
UNEMPLOYMENT    = 1.104 M
PRICES          = 111
B-OF-P          = -535      (X = 4042 M = 4577)
RESERVES        = -485   **CRISIS: BORROW 585 FROM FOREIGN BANKS
NAT DEBT        = 7470      (G = 5200 T = 5337)
                  (-637)
OPINION POLL    = 35%
```

c)

```
YEAR 3

RATE OF TAX ? 35
PLANNED GOVT SPENDING ? 4300

POTENTIAL       = 26118     (I = 5043 S = 4065)
ACTUAL          = 22260     (C = 8432)
GROWTH          = -3.9%
UNEMPLOYMENT    = 1.954 M
PRICES          = 113
B-OF-P          = -251      (X = 4086 M = 4337)
RESERVES        = -151   **CRISIS: BORROW 251 FROM FOREIGN BANKS)
NAT DEBT        = 6744      (G = 4800 T = 5526)
                  (-726)
OPINION POLL    = 21%
```

KEY:

I	: Gross investment in capital goods	T	: Total taxes levied
S	: Savings	C	: Consumption
G	: Actual Government Spending	X	: Exports
		M	: Imports

potential of computer based learning systems and an organisation has been established to advise on, and co-ordinate, the production and use of such material. The type of software being used relates to areas such as population dynamics and industry location under various geopolitical factors.

Many of the offerings in this area are academic games, which are much more sophisticated than pencil and paper systems but still teach the basic skills of decision making and problem solving. The games are often elaborately scored (and computerisation is a bonus for the teacher who no longer has to referee). They are carried out competitively between groups of students who try to assess the available information and decide upon a policy for their 'company'.

The vocational use of computers

Computers have long been used for the purpose of teaching computing. As the number of applications areas has increased, computers are now being used to teach applications functions in other disciplines. Here, computers are used to demonstrate to students the uses to which they are put in the normal practise of a particular subject, rather than as a means of presenting information in a novel and interesting way. In higher education, computers used in this way are usually found in vocational courses such as engineering.

Computer science

Computer science departments and computer centres have always been closely linked for obvious reasons. In America, several universities have signed deals with microcomputer manufacturers and insist that all first year students in computing or engineering – or in the case of one university, all students – must buy one of a particular type of microcomputer. There is at least one university in England which is considering a similar deal based upon a new (British made) microcomputer. Such a scheme can have advantages for both the institution and the student. The micro can be used by the student to complete problems set on the course, without having to compete for scarce terminals. This would also take pressure off the institutional computer centre.

Design studies
Computers are used as tools in almost all areas of design work, and this is reflected in the way that these subjects are now taught.

Computers with colour displays are used to experiment with different patterns in schools of art, and find especial use in the fields of wallpaper and textile design. Computers enable students to compose and merge different designs, keep progress records, and so on. The computer can also be used to drive an ink jet colour printer, or similar device, and to deliver a hard copy output of a sample composition. One art school is using a monochrome graphics system to aid the teaching of sculpture. The 'model' can be viewed through the appropriate transformations in any direction, and this flexibility aids students in their perception and construction of 3-D forms.

Using drafting packages or three dimensional solid modelling programs, students can design complex configurations and obtain top quality drafted results as output. Again this removes the medium of drawing and allows the student to concentrate on the design task itself.

Design systems which can model elements of building design, transformations of viewpoint, walkthroughs, etc. are prominently used by schools of architecture. Computerised drafting is also a great boon in this application.

Computers are also used in electronics tuition, to design components and circuits, while simulation techniques can be used to investigate the behaviour of circuits before construction. Simulations like this are also used in chemical process design, as they enable testing before construction.

These examples show just a few of the subject areas that are taught using systems which reflect the way that design is performed in reality. In common with the other computer activities, the main advantage of these systems is that the computer relieves the worker from mundane mechanical tasks, such as drafting and calculation. It is important that students are exposed to such uses of computers to prepare them for future work.

Left: children are now learning to operate a keyboard at an early age. (Photo: BBC).

Analysing logic systems

In *Digital & Solid State Appendices 6* we noted that the development of increasingly complex systems over recent years has brought with it a corresponding increase in the complexity of the test equipment needed to design, produce and service them. Nowhere is this more apparent than in the case of digital systems, where microprocessor controlled logic circuits now perform complex tasks in the minimum of time.

Below: the Thandar TA2080 logic analyser. (Photo: G.B.C.).

In such systems, the hardware action depends on the software stored within memory. Because of this, signals present within a digital system are rarely repetitive and hence cannot be displayed by a basic oscilloscope. A storage oscilloscope may, perhaps, be used to display some of the signals generated by the system, but no more than just a handful can be successfully analysed in this way, because microprocessor based systems are bus systems and may have many more signal lines than an oscilloscope can display. An 8-bit microprocessor based system, for example, could have around 32 signal lines which must be analysed together.

Test equipment that has been specially developed to cater for the requirements of digital systems are known as **logic analysers.** A logic analyser is itself a microprocessor based device but in practical terms, is merely an extension of the digital storage oscilloscope principle, featuring CRT display of applied signals after the signals have been stored internally.

Logic analysers capable of storing and displaying 8, 16, 32, 64 etc., signals are available, with operating ranges between about 5 MHz and 500 MHz. Obviously, such a wide range of facilities is reflected in a wide variety of prices, so the chosen analyser depends on the exact requirements of the application. Often, in fact, logic analysers are **microprocessor specific** which means that they are designed to analyse the signals associated with one particular type of microprocessor. Sometimes a general purpose logic analyser can be made microprocessor specific with the addition of plug-in hardware.

Timing and state analysis

The concept of a logic analyser as an item of test equipment, designed to display signals present in the system, was originally used simply to observe timing signals. In this respect, the logic analyser formed an extremely useful tool when investigating timing signals of hardware circuit problems. A logic analyser operating in this mode is said to be used for **time analysis**.

More recently, however, logic analysers have become increasingly used to

investigate software problems or bugs. In this mode, a logic analyser is said to be used for **state analysis**.

The majority of modern analysers may be used in both time analysis *and* state analysis mode: in time analysis, signals are displayed as waveforms; in state analysis signals are displayed as mnemonics of the microprocessor's mnemonic language. Some, however, may only be capable of one mode.

Features

Most logic analysers have various triggering facilities allowing them, for example, to display events immediately prior to (as well as after) the trigger event. This is obviously useful for timing problems.

A discrepancy between a required signal and the actual signal is often called a **glitch.** By comparing intended signals with measured signals of a system, therefore, glitches may be used to trigger the logic analyser. A display of the events leading up to the glitch may pinpoint the problem.

Some logic analysers feature time measurement facilities, to allow the user to accurately measure and display time intervals between events.

Often, logic analysers feature a number of clock signal outputs. This is useful when analysing a system which consists of, for example, a number of asynchronously connected subsystems. Alternatively, a clock signal may often be accepted from the system under analysis to enable the logic analyser to operate synchronously.

Word generators within a logic analyser allow specific digital word stimuli to be input to the analysed system. Such a feature allows simulation of external, unavailable, hardware for example, or allows the system hardware to be specifically controlled by the logic analyser.

Logic analysers generally have a bus interface, which allows them to be connected to a large **automatic test equipment** (ATE) system, for use say, in production line testing systems. In such a system, all features and facilities of the logic analyser may be determined and controlled by the ATE via the bus. Reading, and access, of data stored by the logic analyser must also be undertaken via the bus.

Many logic analysers feature an amount of non-volatile storage, which enables front panel control settings and data to be retained while power is off. This is very useful and allows, say, an analyser to be used on consecutive days, without the need for reprogramming after it has been turned off overnight. Typical memory sizes of logic analysers (non-volatile or volatile) are around 1K byte.

Glossary

glitch	discrepancy between intended and actual signal, causing a malfunction
logic analyser	test equipment which is used to test complex logic circuits. Often, logic analysers allow storage and display of up to about 64 different simultaneous signals
microprocessor specific	term used when describing an item of equipment which is designed to operate with one particular type of microprocessor. A microprocessor specific logic analyser may only be used to analyse the signals associated with that particular microprocessor system
state analysis	mode of operation of a logic analyser when it measures signals corresponding to software and displays them as mnemonics. Useful if debugging machine software
time analysis	operating mode of a logic analyser when it measures and displays signals, relating to hardware timing

COMMUNICATIONS

6 Facsimile-2

The baseband signal

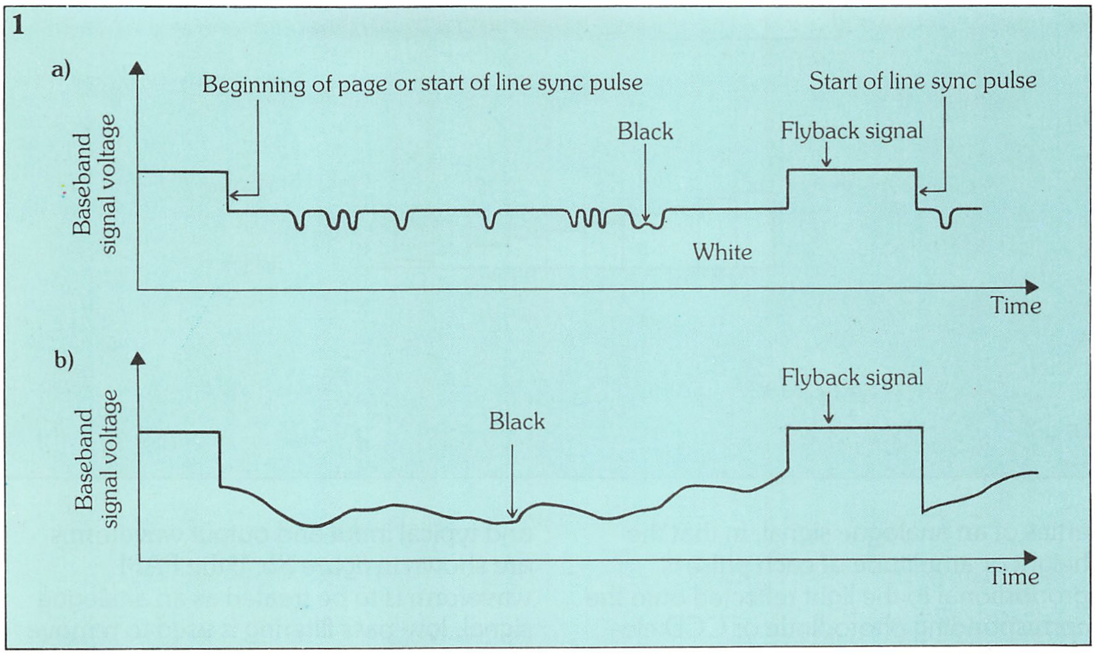
The amplified output of the scanning head, as explained in *Communications 5,* is called the baseband signal, and it is this signal, extracted by demodulation and decoding at the receiver, which drives the printing mechanism.

In all but one of the sensing and scanning techniques examined in *Communications 5,* the baseband is an analogue signal, that is, it varies smoothly and continuously, proportional to the reflected light from the source document. The nature of this baseband signal then, is dependent, to a large extent, on the nature of the source document itself. The signals produced from reading two different classes of source document, a black and white document (for example, a print or line drawing) and a continuous tone document (such as a photograph), are shown in *figures 1a* and *1b* respectively.

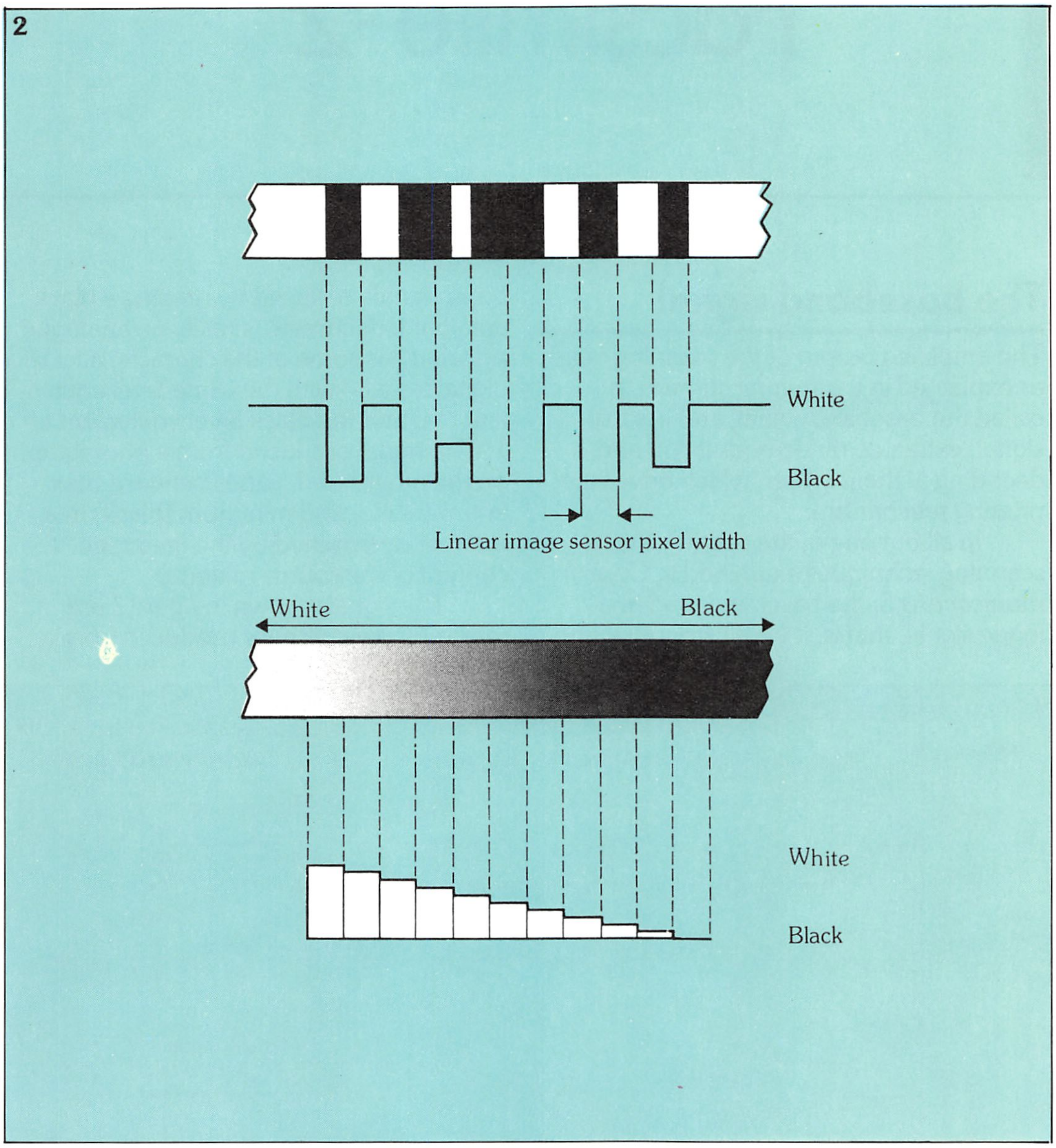
You can see that although the baseband signal produced by reading a black and white document is really an analogue signal, it has some of the characteristics of a digital signal – with the white level equivalent to 0 and the black level equivalent to 1. The signal produced from a photograph, on the other hand, varies between maximum (white) and minimum (black) in a manner determined by the grey tone content of the source material.

The signals shown in *figure 1* are representative of those produced from a one line scan by either a photodiode detector or photomultiplier, a high intensity CRT scanner or a high resolution video camera. The signal produced by a solid state scanner, though, is quite different, as can be seen in *figure 2*. This signal is more complicated, and has a similar appearance no matter whether the source document is black and white or of continuous tone.

The solid state scanner signal looks like a binary digital signal, consisting of a series of pulses, but it also has the prop-



1. Baseband signals produced from: **(a)** a black and white source document, e.g. type or a line drawing; and **(b)** a continuous tone source document, e.g. a photograph. These are representative of signals produced from a one line scan by either a photodiode detector or a photomultiplier.



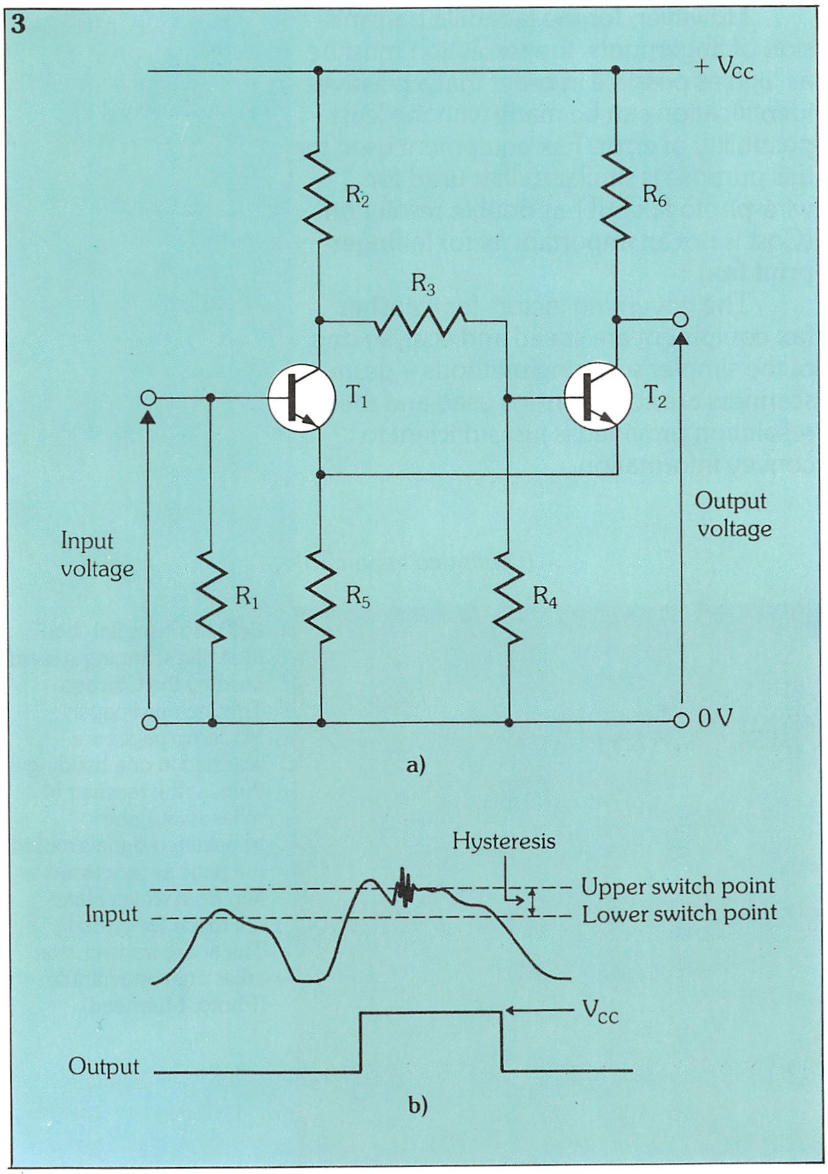
2. Baseband signal produced by a solid state scanner – known as a pulse amplitude modulated waveform.

erties of an analogue signal, in that the height or amplitude of each pulse is proportional to the light reflected onto the corresponding photodiode or CCD element. The output from a solid state scanner is, therefore, known as a **pulse amplitude modulated** (PAM) waveform and can be treated as *either analogue or binary*.

If it is treated as a binary signal, the output is fed into a Schmitt trigger circuit; the output of this kind of circuit, which we looked at in *Digital Electronics 14*, is either a high voltage or a low voltage (but never inbetween) depending on whether the input voltage is above or below certain threshold switching voltage points. *Figure 3a* shows a transistor Schmitt trigger circuit and typical input and output waveforms are shown in *figure 3b*. If the PAM waveform is to be treated as an analogue signal, low-pass filtering is used to remove the clock frequency (which must be higher than twice the greatest signal frequency) and smooth the rectangular pulses.

It is also possible to take a purely analogue signal, such as might be produced by a photodiode or a high resolution video camera, and convert it to a digital signal by the process of analogue-to-digital conversion. As we saw in *Digital Electronics 19* and *20*, an ADC (analogue-to-digital converter) takes a sample of the input waveform at a rate greater than twice the maximum signal frequency, and repre-

3



3.(a) Transistor Schmitt trigger circuit; (b) typical input and output waveforms.

sents the amplitude of each sample as a binary number. The output of a linear image sensor scanner is ideally suited for this type of conversion because each pulse is already a direct sample of the image.

You may be wondering why it is necessary to make distinctions between the various types of analogue signal, and the different ways in which they can be processed. The reason for this is that the type of scanning and sensing method used, and the baseband signal processing which follows, are chosen to meet the particular facsimile application. Generally, this means that the method used is selected to give sufficient resolution for the type of source material, but no more (the limitations of the communications link are also a factor here, as we shall see).

For example, **document facsimile,** the transmission of printed or typed A4 pages, does not require high resolution. The main factors to be considered in document fax transmissions are: the limitations of the public telephone network; speed; and cost (a facsimile transmission over the telephone costs just as much as a conversation for the same time). Linear image sensors are frequently used for document fax, and a special data compression technique is also utilised (this will be dealt with in some detail, later in the article).

The requirements for **newsfax** (where complete newspaper pages are sent to be printed at a distant location) are quite

Right: Pitney Bowes' Model 8800 facsimile machine can transmit an A4 page in only 20 seconds. It is also fitted with an auto-dialler – this stores up to 50 telephone numbers and can be programmed to send documents when rates are cheapest.

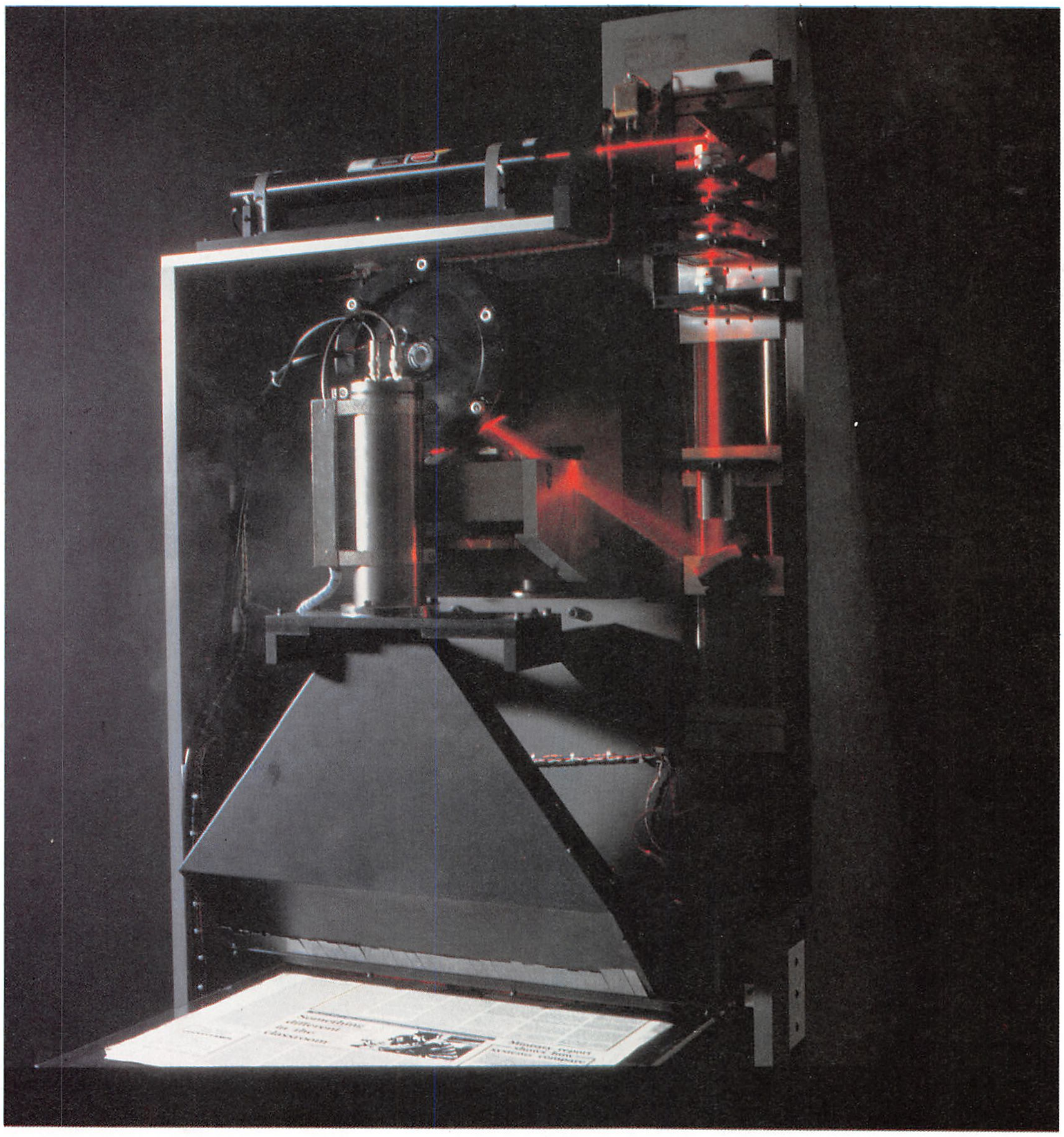
The Research House/Pitney Bowes plc

different, however. Speed is also important, but the resolution must be much higher, because the facsimile document is used as the printing master. Newsfax equipment, therefore, invariably uses one of the sensing and scanning methods that produce a pure analogue signal, such as, laser scanning. The analogue baseband is then converted to a digital representation by an ADC, after which a data encoder is used to compress the amount of information contained in the signal. This allows the transmission to be sent via a standard communications link (such as the telephone network) in a reasonable time. **Wire-photo fax** (the transmission of photographs, generally news pictures) requirements are similar.

However, for the facsimile transmission of fingerprints, the resolution must be as high as possible in order that a positive identification can be made with the least possibility of error. Fax equipment used for this purpose is similar to that used for wire-photo fax but has double resolution. (Cost is not an important factor in **fingerprint fax**).

The governing factors for **weather fax** equipment are speed and cost, so one of the simpler scanning methods – drum scanners are common – is used and the resolution provided is just sufficient to convey information.

(continued in part 36)



Left: the laser flat- bed facsimile scanning system used by the Chicago Tribune newspaper. Made-up pages are scanned in one building then, at the receiver (4 miles away), the transmitted signals record the page as processed film from which plates are made for printing. The entire transmission takes only one minute. (Photo: Muirhead).